PB-242 091

CONSULTANT REPORT ON FIELD PERFORMANCE OF EMISSIONS-CONTROLLED AUTOMOBILES

R. Robert Brattain, et al

National Research Council

Prepared for:

Environmental Protection Agency

November 1974

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

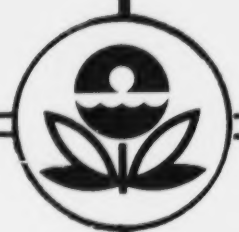
163033

PB 242 091

FIELD PERFORMANCE OF EMISSIONS - CONTROLLED AUTOMOBILES

CONSULTANT REPORT TO THE:
Committee on Motor Vehicle Emissions
Commission on Sociotechnical Systems
National Research Council

SEPTEMBER 1974



U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
US Department of Commerce
Springfield, VA. 22151

PB 242091

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle Consultant Report on Field Performance of Emissions-Controlled Automobiles			5. Report Date November 1974 6.
7. Author(s) R. Robert Brattain, Jack L. Gockel, D. James McDowell			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Committee on Motor Vehicle Emissions Commission on Sociotechnical Systems National Research Council 2101 Constitution Avenue, N.W., Washington, DC 20418			10. Project/Task/Work Unit No. 11. Contract/Grant No. 68-01-0402
12. Sponsoring Organization Name and Address Mobile Source Air Pollution Control U.S. Environmental Protection Agency 401 M Street, S.W. Washington, DC 20460			13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstracts

An evaluation was made of the feasibility of maintaining the automotive emissions control systems and engines which will be manufactured to meet various exhaust-emissions standards for oxides of nitrogen, hydrocarbons, and carbon monoxide so that these systems and engines will meet the standards in actual use. The present condition of the service industry, progress toward enforcing proper maintenance, and the impact of political actions and social attitudes on progress are discussed.

17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

PRICES SUBJECT TO CHANGE

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited availability from NTIS for sale to public	UNCLASSIFIED	86
	20. Security Class (This Page) UNCLASSIFIED	22. Price 4.75/2.25

FORM NTIS-35 (REV. 3-72)

THIS FORM MAY BE REPRODUCED

USCOMM-DC 14952-P-72

CONSULTANT REPORT

to the

Committee on Motor Vehicle Emissions

Commission on Sociotechnical Systems

National Research Council

on

FIELD PERFORMANCE OF EMISSIONS-CONTROLLED AUTOMOBILES

PREPARED BY:

R. Robert Brattain, Chairman

Jack L. Gockel

D. James McDowell

Washington, D.C.

November 1974

ia

NOTICE

This consultant report was prepared by a Panel of Consultants at the request of the Committee on Motor Vehicle Emissions of the National Academy of Sciences. Any opinions or conclusions in this consultant report are those of the Panel members and do not necessarily reflect those of the Committee or of the National Academy of Sciences.

This consultant report has not gone through the Academy review procedure. A preliminary version was reviewed by the Committee on Motor Vehicle Emissions to determine its suitability as a partial basis for the report by the Committee. The final version was received too late to be reviewed again before making it available in this published form.

The findings of the Committee on Motor Vehicle Emissions, based in part upon material in this consultant report but not solely dependent upon it, are found only in the Report by the Committee on Motor Vehicle Emissions of November 1974.

PREFACE

The National Academy of Sciences, through its Committee on Motor Vehicle Emissions (CMVE), initiated a study of automobile emissions-control technologies at the request of the United States Congress and the Environmental Protection Agency (EPA) in October 1973. To help carry out its work, the CMVE engaged panels of consultants to collect information and to prepare consultant reports on various facets of motor vehicle emissions control. This Consultant Report on Field Performance of Emissions-Controlled Automobiles is one of five consultant reports prepared and submitted to the Committee in connection with the Report by the Committee on Motor Vehicle Emissions of November 1974. The other consultant reports are:

An Evaluation of Catalytic Converters for Control of Automobile Exhaust Pollutants, September 1974

Emissions and Fuel Economy Test Methods and Procedures, September 1974

Emissions Control of Engine Systems, September 1974

Manufacturability and Costs of Proposed Low-Emissions Automotive Engine Systems, November 1974

These five consultant reports are NOT reports of the National Academy of Sciences or its Committee on Motor Vehicle Emissions. They have been developed for the purpose of providing a partial basis for the report by the Committee as described more fully in the cover NOTICE.

This consultant report was prepared by R. Robert Brattain, Jack L. Gockel and D. James McDowell with R. Robert Brattain acting as principal author. Valuable assistance was furnished by G.C. Hass in reading and criticizing the original draft. Messrs. Gockel and McDowell deserve recognition for their contributions. The principal author must take responsibility for the final form of the report and for any mistakes.

CONTENTS

1. Summary..... 1

2. Conclusions..... 3

3. Introduction..... 5

4. Feasibility of Manufacturing Cars Capable of Meeting the Standards, If Properly Maintained..... 11

5. Present Condition of the Service Industry..... 18

6. Lack of Progress toward Enforcing Proper Maintenance..... 24

7. Probability That the 1975-76 Cars Will Meet the Standards under Existing Maintenance Conditions..... 28

8. Effect of Untreated Exhaust on Average Emissions..... 41

9. Impact of Political Actions and Social Attitudes..... 53

10. Maintenance Impact of Unleaded Fuel..... 56

11. Durability Improvements in Emissions-Related Components.... 57

12. Possible Regimes for Ensuring Proper Maintenance..... 58

13. Differences in Maintainability Resulting from Different Engines, Emissions-Control Systems, or Fuels..... 68

Appendix A..... 77

1. SUMMARY

This report on field performance and maintenance of new cars is essentially an update of the maintenance part of the earlier report by the Panel on Testing, Inspection, and Maintenance.[1*] It builds on that report in analyzing the probability that the 1975-76 cars will meet the exhaust-emissions standards in actual use in customers' hands. The first major question addressed is whether the 1975-76 vehicles would meet the standards, if properly maintained. Results of certification tests, fleet test data, component improvements, and the effect of unleaded fuel are all considered and the question is answered affirmatively. The probability that the cars will receive proper maintenance is next examined in terms of the present state of the service industry and the availability of regimes for enforcing proper maintenance. It is concluded that they will not receive proper maintenance because the service industry is inadequate, and means for enforcing proper maintenance do not exist. The effect of improper maintenance on the probability of meeting the standards is next analyzed, and it is concluded that 1975-76 cars will not meet the standards in actual use, although they will come closer than other recent model cars. An analysis of the sensitivity of emissions to the presence of untreated exhaust shows that proper maintenance will become more essential for meeting the standards as the standards become stricter.

The reasons for the lack of progress in establishing regimes for enforcing proper maintenance and for the present state of the service industry are examined next, and it is concluded that fundamental social attitudes, not technical difficulties, have been the major stumbling blocks to the improvement of both situations. The effects of component reliability and the use of unleaded fuel on maintenance required are evaluated and these factors are found to be the major reasons why 1975-76 cars will come closer to meeting standards than recent cars. A classification of possible regimes for ensuring proper maintenance is presented and the three basic types are compared. It is concluded that the type which could be instituted most quickly is precluded by a social attitude, distrust

* References are listed at the end of the report (page 75).

of mechanics, and that the most popular regime, inspection/maintenance, has not been evaluated closely enough. It may have faults which make it less attractive than is commonly believed.

The report concludes with an analysis of alternatives to the gasoline internal combustion engine from the standpoint of required maintenance, and it is concluded that none of the near-term alternatives offer significant advantages.

2. CONCLUSIONS

1. It is feasible to manufacture cars which, if properly maintained, are capable of meeting the 1975-1976 exhaust-emissions standards in actual use for 50,000 miles.

2. The service industry is not adequate to perform proper maintenance of 1975-1976 cars, but there are growing efforts toward self improvement.

3. There has been a noticeable lack of progress, during the last two years, toward establishing regimes to ensure proper maintenance and, consequently, such regimes do not exist.

4. The 1975-1976 exhaust-emissions standards will not be met in actual use because the proper maintenance will not be performed (see 2 and 3 above). The margin by which they fail may be small.

5. Proper maintenance becomes more important as emissions standards become stricter, because untreated exhaust increases the percentage by which actual emissions exceed allowed emissions more rapidly than linearly as the required efficiency of control devices increases.

6. The absence of regimes for ensuring proper maintenance and the present state of the service industry are both the results of social and political attitudes and are not the results of technical limitations.

7. The use of unleaded fuel will materially reduce the maintenance which a vehicle requires.

8. The 1975-1976 cars will probably come closer to meeting the standards than ones manufactured in the last few years, and this is particularly true for those using catalytic control systems.

9. It is possible to hypothesize regimes for ensuring proper maintenance, but it is impossible to implement any of them in a significant number of states until after 1980 at the earliest.

10. There do not appear to be any engine-control-system combinations which are clearly superior in meeting the standards under the present inadequate maintenance situation.

3. INTRODUCTION

3.1 Report Organization

The main body of the report which follows this Introduction is divided into ten sections, each one of which discusses the evidence and reasoning supporting one of the conclusions in the order which they have been stated above. It should be emphasized that the sections which follow "discuss the evidence and reasoning which support the conclusions"--the sections do not prove the conclusions. By definition, data on behavior in actual use do not exist for cars still to be manufactured and sold. Consequently, it is impossible to prove, in the usual sense, how these cars will function in the real world. However, the evidential situation is much better than when the previous report by the Panel on Testing, Inspection, and Maintenance[1] (see Subsection 3.3, Scope) was written. It is better because many prototype vehicles have now passed the Certification Test Procedure, data are available on the performance of catalytic converters under semi-real-world conditions, and it is possible to estimate the probability that cars will be properly maintained in the near future by examining what progress has been made in the last two years.

This Introduction contains two short sections on Purpose and Scope and then concludes with a discussion of the definition of meeting the exhaust-emissions standards--a definition which seems obvious, but which is often not adhered to, even though a clear definition of the meaning of this term is basic not only to this report but also to any discussion of exhaust-emissions control.

3.2 Purpose

The purpose of this report on field performance and maintenance is to evaluate the feasibility of maintaining the systems and engines which will be manufactured to meet various exhaust-emissions standards for

nitrogen oxides (NO_x), hydrocarbons (HC) and carbon monoxide (CO) so that these systems and engines will meet the standards in actual use.

3.3 Scope

This report is an extension, on the basis of more recent information, of part of a report entitled "Feasibility of Meeting the 1975-1976 Exhaust Emission Standards in Actual Use," June 1973, prepared at the request of the Committee on Motor Vehicle Emissions of the National Academy of Sciences.[1] It was prepared by the Panel on Testing, Inspection and Maintenance using data obtained prior to September 1972. It will be referred to as the "Panel 2 Report." This earlier report discussed both the maintenance of vehicles in use and the testing procedures used to determine exhaust emissions at all stages of development, production and use. The present study has been divided between two reports: "Emissions and Fuel-Economy Test Methods and Procedures" and "Field Performance and Maintenance".

Much of what was said in the Panel 2 Report has not changed. Consequently, this report has been restricted to a discussion of the information obtained between September 1972 and the middle of 1974, and to the conclusions which can be based on this more recent information. References will be made to the Panel 2 Report where continuity with the earlier work is important.

Some items closely related to maintenance of cars have <u>not</u> been included in this report. The total cost of any of the hypothetical regimes which might ensure proper maintenance has not been calculated. Only a calculation of real total cost has meaning and such calculation is complicated almost to the point of impossibility. It would need to include, but not be limited to, cost of designing and producing the vehicles, cost of fuel over the vehicle's life, cost of upgrading the service industry, cost of operating the governmental control agency, cost of maintenance beyond that needed to keep the car operative, and cost of any new construction required for maintenance or inspection facilities. Purported

costs of various maintenance regimes have been published, but, in general, these have not been real total costs and the calculations often appear to have been maneuvered to support a favorite position.

Since costs have not been calculated, the cost effectiveness of proper maintenance as a means of reducing the pollutant burden has also not been calculated. Nothing in this report should be interpreted as stating or implying that proper maintenance is more or less cost effective than other possible methods of reducing the pollutant burden. For the same reasons, nothing in this report should be taken as indicating that one maintenance regime is more or less costly than another.

3.4 Definition of Meeting the Exhaust-Emissions Standards

A definition of meeting the exhaust-emissions standards must be based on the answers to two questions:

-To what exhaust emissions do the standards apply?

-What method will be used to measure these emissions?

The answer to the first question follows directly from the purpose of exhaust-emissions standards; namely, to reduce the automotive contribution to air pollution. Since the automotive contribution to the air-pollutant burden is determined by the number of cars being driven and the emissions from the average car, the standards must apply to the emissions from the average car in use to have any meaning in terms of the basic purpose of exhaust-emissions control.

The fact that standards can only be considered to be met if they are met by cars in use seems obvious, but this fact or its more important implications are consistently ignored in discussions of automotive emissions control. The most common method of ignoring this basic fact is to discuss the problem solely in terms of designing and manufacturing cars which meet strict emissions standards when new. This is not sufficient, if there is not some method of ensuring that cars will continue to be low emitters during their useful lives. Simple neglect, intentional

device deactivation, maladjustment, and deterioration between service intervals are likely to have such overriding effects that they become the real determinants of the vehicle contribution to pollution rather than the mechanical design of the engine and control system. Certainly in those states where it is legal to disconnect emissions-control devices, and where advertisements urge owners to do so, the air pollution from cars will not be determined solely by the mechanical features and the control systems when the cars leave the assembly line.

The importance of this concept is recognized in the Clean Air Act[2] of 1970* by setting exhaust-emissions standards as standards which must be met for 50,000 miles of use, not as standards which must be met at the end of the assembly line. However, the importance of starting with a good mechanical system is also recognized by specifying that a class** of vehicles cannot be sold unless the testing of prototypes has demonstrated that cars so designed are capable of meeting the standards for 50,000 miles, if properly maintained. However, in spite of the logical importance of the concept and the clear legal statement of the meaning of the standards, the numerical values which apply at 50,000 miles of use are consistently used as if they were standards which the cars should meet at lesser or zero mileage.

Quantities of pollutants emitted or numbers stated as exhaust-emissions standards have meaning only in terms of the specific analytical procedure used to determine them. A specific procedure for this purpose has been legally described--the Federal Test Procedure (FTP). In this report the phrase "meet(ing) the standards" means that "the average emissions from a class of vehicles, as measured by the FTP, remain at or below the

---

* Hereinafter referred to as the Act.

** Class is used to mean similar vehicles produced by the same manufacturer and equipped with the same engine and control system. Although class is not specifically defined in the Act, it is clearly used in this sense; e.g., Section 202(a)(1) and 207(c)(1).

applicable standards for 50,000 miles of actual use under real-world conditions." If the FTP does not accurately reproduce the conditions of normal use, the emissions measured may be different from the quantities emitted during normal use. This point is important from the standpoint of the primary objective of reducing the pollutant burden and it is discussed in the "Consultant Report on Emissions and Fuel Economy Test Methods and Procedures".[3] It is, however, not germane to this report and the strict definition, given above, of meeting the standards will be used throughout.

Average emissions are used in the definition as the logical basis since, as stated above, automotive air pollution is determined by the product of the number of vehicles and the emissions from the average car. The other possible basis for the definition; namely, that every car meet the standards, is not logical in terms of the primary objective and leads to many procedural difficulties, if used as the basis for a maintenance regime (see Ref. 1, pp. 80 to 87).

H.R. 14368, which became Public Law No. 93-319 when signed by the President on 22 June 1974, sets the exhaust-emissions standards which light-duty motor vehicles must meet for 50,000 miles as:

	HC	CO	NO_x
	In grams per mile		
1975 Federal	1.5	15.0	3.1
1975 California	0.9	9.0	2.0
1976 Federal	1.5	15.0	3.1
1976 California	0.9	9.0	2.0
1977 Nationwide	0.41	3.4	2.0
1978 Nationwide	0.41	3.4	0.4

The 1977 HC and CO standards could be delayed one year by action of the EPA Administrator, and California can ask for a waiver for a stricter NO_x standard in 1977.

The above 1975 and 1976 standards should be compared with the original 1975 and 1976 standards:

	HC	CO	NO_x
1975 Federal	0.41	3.4	3.1
1976 Federal	0.41	3.4	0.40

These more stringent standards have now been delayed until 1977 and 1978.

4. FEASIBILITY OF MANUFACTURING CARS CAPABLE OF MEETING THE STANDARDS, IF PROPERLY MAINTAINED

This section presents the evidence and reasoning supporting Conclusion 1: It is feasible to manufacture cars which, if properly maintained, are capable of meeting the 1975-1976 exhaust emissions standards in actual use for 50,000 miles. The evidence is in three groups; namely, certification test results, data from fleet tests, and the improved durability of components. The first two items will be discussed in this section following a brief paragraph describing the probable 1975-76 emissions-control configurations, and the improvements in durability will be discussed in Section 11.

4.1 Probable 1975-76 Emissions-Control Configurations

The information in the Consultant Report on Emissions Control of Engine Systems[4] indicates that most of the cars manufactured to meet the 1975-76 standards will be powered with conventional gasoline engines. Control of hydrocarbon and carbon monoxide emissions will be accomplished in most cases with an oxidation catalyst. Control of nitrogen oxides will be primarily by exhaust gas recirculation (EGR) and secondarily by spark retard and air/fuel ratio. The control systems will often include special carburetors, quick-heat manifolds, and other engine modifications to reduce the HC and CO emissions to the catalyst. Air pumps will be used on California vehicles and other engines with HC and CO emissions too high to be controlled by engine modifications and catalyst alone. A smaller percentage of vehicles will be powered by diesels, rotary engines with exhaust manifold reactors and EGR, and stratified-charge engines (both with and without catalysts). It appears that up to 20% of the cars may not use catalysts and, consequently, may be fueled with leaded gasoline. See Reference 4 for the details on any of these systems and for the probable distribution of the production among types.

4.2 Certification Test Results

The results presented in Reference 4 show that the proposed 1975 cars can meet the standards for 50,000 miles under the conditions of the official Certification Test Procedure. This statement applies equally to catalytic and non-catalytic control systems. The relaxation of the standards from the original 1975 values to the values now applicable in the 49 states made possible the use of non-catalytic systems on some classes of conventional piston engines. It should be noted that some of the unconventional engines without catalysts, as well as conventional engines with catalysts, met not only the standards for the 49 states but also the stricter California standards and that some of the catalyst-equipped cars were close to meeting the 1977 standards of 0.41 g/mi HC, 3.4 g/mi CO, and 2.0 g/mi NO_x at extended mileage.

The high degree of success during certification testing of catalytic systems can be attributed to improved catalyst containers, improved catalysts, and lower maintenance requirements because of unleaded fuel. Catalytic-converter failures were infrequent. When they occurred, the causes were usually attributable to the failure of prototype ignition or fuel-system parts. It appears that the mechanical, structural, and thermal problems of catalytic converters have been solved for engines that receive good maintenance and do not experience abnormal failures of the ignition and fuel systems.[5] These results are in contrast to those reported in the Panel 2 Report (Ref. 1, p. 54). At that time, none of the manufacturers reported vehicles which had successfully completed the 50,000-mile Durability Driving Cycle. However, Universal Oil Products reported to Panel 2 that they had met the original 1975 standards at 52,000 miles with a base-metal catalyst in a standard General Motors (GM) 260 cu in. converter on a 1972 Chevrolet with a 350 CID engine. They also reported emissions significantly below the requirements at 32,200 miles with a low-platinum catalyst in the same configuration. Both tests were run with an exceptionally clean fuel (p. 57 of Ref. 1).

It appears that the primary reason for the significantly better durability results with catalytic systems is not the relaxation of the HC and CO standards. The certification data on the California vehicles show that HC and CO standards more stringent than the present federal standards can be met with existing systems and the certification data already cited clearly indicate that the present systems can essentially meet the 1977 standards. In addition, Universial Oil Products presented an impressive amount of durability data,[6] accumulated with their oxidation catalysts, which indicate that the original federal standards of 0.41 g/mi HC and 3.4 g/mi CO can be met without catalyst change and with the use of the EPA specified fuel. These results show that stricter HC and CO standards can be met in the future with essentially the same equipment as that planned for 1975; i.e., with systems which will not significantly change the maintenance required.

There are no data which show compliance with the original standard for NO_x of 0.40 g/mi for 50,000 miles, but there are data showing that this standard can be met for 25,000 miles. Robert Bosch GMBH of Stuttgart, West Germany has achieved emissions below the 1978 standards (0.41/3.4/0.40) for almost 25,000 miles with a three-way catalyst and a feedback system to control air/fuel ratio on a 1.9 liter engine in a 2,300 lb car driven on a road cycle.[7] The NO_x emissions started to increase sharply at about 22,000 miles, but Bosch does not think that catalyst deterioration was the cause. They stated that they no longer consider the durability of three-way catalysts a serious problem and that they have oxygen sensors for the control loop which they will guarantee for 15,000 miles.

Gould on 9 July 1974[8] also stated to the Engine Systems consultants that they can achieve the 1978 standards with their system, which consists of a small oxidation catalyst followed by a reducing catalyst which, in turn, is followed by the main oxidation catalyst. At just past 25,000 miles they had met the 1978 standards with a small car and had achieved 0.41/3.4/1.0 g/mi with normal-size cars. General Motors[9] has also met the 1978 standards with three-way catalysts and closed-loop air-fuel ratio control

on both small and large cars, but their data were all at low mileage. It should be noted that the GM tests showed no loss in fuel economy and GM stated that the three-way catalyst system is the only means of achieving low NO_x emissions without a fuel penalty; an opinion apparently shared by other manufacturers. Since such systems require feedback control of the A/F ratio, and/or additional catalysts, it is probable that achieving low NO_x emissions would introduce more maintenance problems, even though the results indicate the feasibility of the 1978 standards, perhaps with a catalyst change.

4.3 Field-Test Data

A significant amount of field-test data on vehicles with catalytic converters also supports the conclusion that cars equipped with catalytic control systems will meet the standards, if properly maintained. These field vehicles were operated under conditions more representative of customer use, but not completely so. It is important to note that these test fleets were supervised and received proper maintenance.

4.3.1 General Motors fleets--General Motors is conducting several field tests on experimental catalytic converters. Two of the test fleets pertinent to 1975 in-use durability are in moderate to high mileage service by the California Division of Highways and in high mileage taxicab operation at different locations. Emissions data[10] on 25 Oldsmobiles at the California Division of Highways are shown in Table 4.1. Thirteen of the vehicles are adjusted lean enough to eliminate the need for the air pump. The other twelve vehicles are equipped with air pumps. These vehicles are fueled from a fueling facility at the Division of Highways garage and by commercial stations. All 25 vehicles use the under-floor catalytic converter configuration certified for GM cars in 1975. They receive periodic maintenance by a well supervised garage. The data show the feasibility of meeting low HC and CO standards at the 2.0 g/mi NO_x

TABLE 4.1

EXHAUST-EMISSIONS TEST SUMMARY

CALIFORNIA DIVISION OF HIGHWAYS

UNDER-FLOOR CONVERTER FLEET

13 Oldsmobiles Without Air Pumps

Average Test Mileage	No. of Cars	1975 EPA g/mi[1] HC	CO	NO_x
194	13	0.19	1.90	1.75
4,108	13	0.20	2.22	1.86
8,222	13	0.24	2.14	1.84
12,296	5	0.25	2.83	1.75
16,022	13	0.24	2.87	1.79
20,535	5	0.23	2.13	1.72
24,976	3	0.21	3.16	1.93
25,348[2]	4	0.19	1.76	1.81

12 Oldsmobiles With Air Pumps

Average Test Mileage	No. of Cars	1975 EPA g/mi[1,2] HC	CO	NO_x
230	12	0.30	0.91	1.48
4,426	12	0.31	0.98	1.62
8,620	12	0.31	1.21	1.72
14,803	2	0.45	1.41	1.56

NOTES: 1) Official Federal Test Procedure

2) Procedure which eliminates effect of engine degradation

Ref. 10

level under the proper maintenance conditions.

Results[10] on two taxicab fleets are shown in Figure 4.1. Both groups use the under-floor catalytic converter certified for 1975 GM cars. Group 1 is designed to meet the 1975 federal standards and Group 2 the 1975 standards. Although neither fleet has quite completed 50,000 miles, the data indicate that these vehicles will meet the standards for which they were designed. These fleets were fueled from easily controlled central facilities and, consequently, the danger of catalyst-activity loss from lead poisoning was minimized.

4.3.2 Ford field test--Ford placed 450 vehicles in lease-car fleets in California. This service was reasonably representative of customer service except that the availability of unleaded fuel was poorer than is expected at the time of 1975 vehicle sales. The vehicles were fueled at commerical stations marketing unleaded fuel. At 12,000 miles, the average emissions[11] of the total fleet in grams/mile were:

HC = 0.30 CO = 1.35 NO_x = 2.38

These results again support the conclusion that 1975-76 vehicles have the capability of meeting 1975 HC and CO standards (and even lower) if they are properly maintained.

4.4 Reductions in Required Maintainenance

The conclusion that vehicles can be manufactured with the capability of meeting the 1975-76 standards is also supported by a reduction in required maintenance which results from improved components and the use of unleaded gasoline. These items will be discussed in Sections 10 and 11.

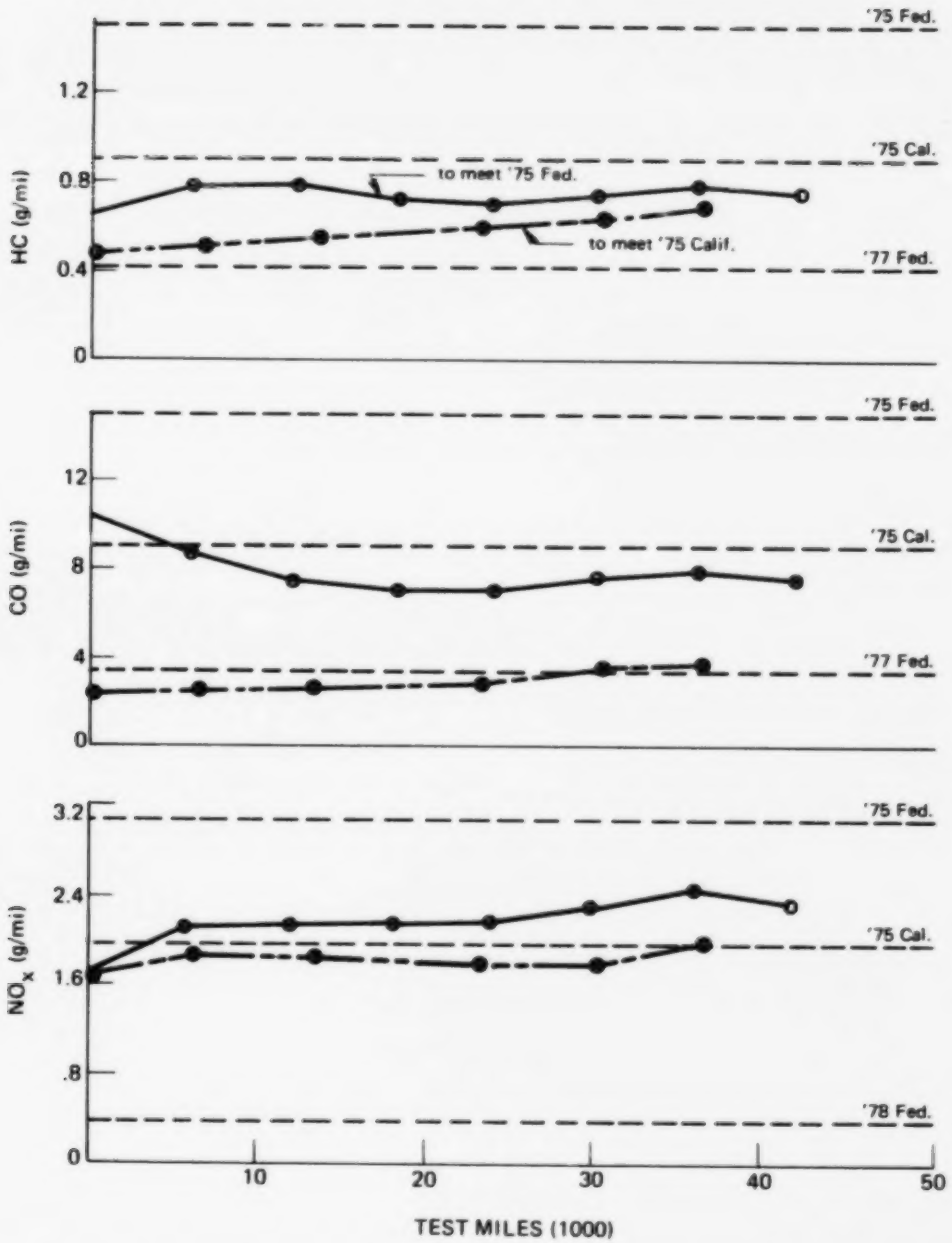


FIGURE 4.1 Emission Status--Copo Fleet, Average of Cars in Each Group--4 June 1974

REF. 10

5. PRESENT CONDITION OF THE SERVICE INDUSTRY

This section presents the evidence and reasoning supporting Conclusion 2: The service industry is not adequate to perform proper maintenance of 1975-76 cars, but there are growing efforts toward self improvement. The evidence is in four categories: number of mechanics, skill level of mechanics, service facilities, and certification of mechanics.

5.1 Introduction

The only action which reduces the emissions from a car with inoperative control devices or with a maladjusted engine is the repair or adjustment of that car by a well-equipped and competent mechanic. This fundamental fact seems to be consistently ignored in general discussions of automotive emissions and, even more alarmingly, in discussions of various state programs for enforcing mandatory maintenance. Enforcement of proper maintenance by regulatory action and performance of the maintenance recommended by the manufacturers are both ineffective in reducing emissions without an adequate service industry. Furthermore, the fact that there will not be mandatory enforcement of proper maintenance in most of the critical air basins before 1980 at the earliest (Section 6) makes it even more important that whatever maintenance is done be done correctly. The existing service industry is not able to fulfill this essential role because of shortcomings in number, skill level and facilities.

5.2 Number of Mechanics

There is no agreement on the exact number of mechanics in the United States, but there is complete agreement on the fact that the number is too small. The Automotive Service Industry Association[12] (ASIA) places the number at about 850,000, a number apparently accepted by the many organizations represented at the National Automotive Service

Vocational Education Conference in 1973. ASIA believes that this figure is 225,000 below the number needed now and points out that 25,000 mechanics are needed per year to replace those who retire or drop out. The above-mentioned Conference agreed that about 87 vehicles per mechanic is the proper number. The Automotive News Almanac for 1974 states that there are 101,237,000 passenger cars and 23,241,000 trucks and busses in the United States. If there are 850,000 mechanics, there are 146 vehicles per mechanic and 225,000 more mechanics would give 115 per mechanic. An increase of 581,000 would be needed to give 87 vehicles per mechanic.

The Department of Transportation[13] stated in June 1971 that the number of cars per mechanic had increased from 75 in 1950 to 145 in 1970, in excellent agreement with the 146 calculated above. Since there were a few more than 108,000,000 motor vehicles in the United States in 1970, this is equivalent to an estimate of about 748,000 mechanics. The Bureau of Labor Statistics gives 800,000 as the number of mechanics on the basis of the 1970 census.

Herbert S. Fuhrman, President of the National Institute for Automotive Service Excellence (NIASE), objected to this figure as misleading.[14] He stated that the 800,000 should be reduced by 265,000 mechanics who are not available to work on private cars because they are employed by government agencies, public utilities, and the like. If, in addition, the heavy-duty, part-time, and very-low-income groups are eliminated, there are less than 500,000 mechanics left who are available to service private cars. Mr. Fuhrman estimated that about 200,000 of these could pass the NIASE test with some preparation.

There appears to be general agreement on 800,000 to 850,000 total mechanics. An estimate of about 200,000 who would be competent to adjust cars for low emissions also seems to have general support, since Mr. Fuhrman's estimate agrees with the 25% of 850,000 total which the ASIA estimated could pass the NIASE test with some study. Mr. Fuhrman's estimate of about 500,000 total available for work on private cars also agrees with the estimate made by the Service Research group at General Motors.[15]

It should be remembered that all of these numbers games are of questionable validity. However, for estimating purposes, the 87 cars per mechanic appears to be approximately correct (74 and 68 are the numbers in Japan and England) and this combined with the total number of passenger cars (101,237,000) gives about 1,160,000 as the number of mechanics needed. This is a total figure and it includes many mechanics other than those who would be responsible for determining and correcting the causes of excess emissions, usually called tune-up mechanics. If allowance is made for the distribution of emissions-control work between dealerships and other garages, about one third of the mechanics should be qualified on emissions controls. On this basis about 388,000 of the 1,160,000 total should be qualified. Both of these figures are approximately twice the 200,000 and 500,000 estimated above as the number who could qualify with moderate study and the total number available for work on passenger cars. Even with the admitted inaccuracy, these estimates support the generally accepted belief that there is a serious shortage.

5.3 Skill Level of Mechanics

The previous subsection discusses not only the shortage of mechanics but also the shortage of well-trained ones. There is general agreement on the need to improve the skill level of the present mechanics; e.g., the two independent estimates that only about 25% could pass a good examination after some review. The deficiencies in training are particularly noticeable in the new field of emissions control.

5.4 Service Facilities

The service facilities must be upgraded both in equipment and operational methods to ensure proper maintenance. Most of the dealerships and better service garages have all of the required equipment except infrared analyzers. Such equipment is required in some states and strongly encouraged in others. Supporting items such as calibration gases, service manuals, engine

specifications, etc. are also needed. The equipment problems are, however, all technical in nature and should offer difficulty only in the smaller shops. Perhaps more difficult to achieve but perhaps even more important is the creation of a work environment and operating philosophy that encourages good work. The most thorough training program would be wasted, if the work environment caused the mechanic to attempt to abuse the flat-rate pay schedule with improperly performed work or work not done.

5.5 Certification Or Licensing of Mechanics

There appears to be a changing attitude in the United States toward the certification and/or licensing of mechanics. The service organizations, among others, have traditionally opposed licensing of mechanics and this position has been politically supported. The argument has been that many mechanics, whose knowledge is purely practical, would be at a disadvantage in any examination which depended even partially on a written examination. Now two of the largest industry groups[16] are actively backing voluntary certification through the NIASE tests. In addition these groups believe that there is a trend toward governmental licensing and intend to assist in the drafting of good legislation. Their representatives stated flatly that the image of the practical mechanic who has difficulty understanding the written word is nonsense at this time.

Many of the control agencies contacted are thinking about licensing--a subject hardly mentioned two years ago--but there has been only one instance of definite action. The Michigan legislature passed a bill in June requiring the state licensing of mechanics.

Licensing of mechanics is quite common in other countries. In Canada, anyone who accepts pay for repairing a car is subject to criminal penalties unless he has a license from either the Province in which the work is done or from the federal government. Requirements vary among the Provinces, but more and more mechanics are taking the examination to obtain a federal license good anywhere in Canada.

In England, mechanics are trained under a scheme proposed by the National Joint Council for the Motor Industry and approved by the Road Transport Industry Training Board. The training, which is part apprenticeship and part class work, lasts four years at the end of which the mechanic is certified. If later he passes a special test of practical skills and examinations on theoretical knowledge of motor technology, he receives a National Craftsman Certificate from the government.

In Germany, the training consists of three years' apprenticeship at the end of which an examination is given by the local industry (the closest group in the U.S. would be the local Chamber of Commerce). Those who pass get a journeyman rating, and after additional experience, the journeyman can take an examination for a Meister rating. The state licenses garages and every garage must have at least one Meister.

In Japan, all mechanics are licensed by the central government. After two years of practical experience as an apprentice it is possible to take a written and hands-on test, which if passed, results in the applicant receiving the bottom grade of license. After an additional two years' experience, or after successfully completing a two-year technical junior college course, a licensed mechanic can take an additional written and hands-on test to qualify for the middle grade of mechanic. The top grade is at present unoccupied, but it will probably be reserved for instructors. These tests and licenses are all given by the Ministry of Transport, which is also in charge of the mandatory maintenance regime. As will be seen later, these licensed mechanics are the heart of the Japanese mandatory maintenance regime.

As noted above, the opposition to certification or licensing appears to be diminishing in the United States. The NIASE program of voluntary certification is gaining momentum. Almost twice as many mechanics took and passed tests in May 1974 as in any of the earlier three test series. In the first two years of NIASE[17] operations they have given four series of tests in over 200 cities. About 40,000 mechanics have passed one or more of the eight tests and about 8,000 have passed all eight tests to

obtain the top certificate as General Automobile Mechanic. NIASE publishes a directory which lists 5,300 garages in every state in the union where certified mechanics are employed. This program may form the foundation for the needed upgrading. On the basis of experience in other countries licensing should not only improve the chances of meeting the standards, but should also improve the status of the mechanics in the eyes of the public. The importance of this last item will be discussed in Section 9.

6. LACK OF PROGRESS TOWARD ENFORCING PROPER MAINTENANCE

This section presents the evidence and reasoning supporting Conclusion 3: There has been a noticeable lack of progress, during the last two years, towards establishing regimes to ensure proper maintenance and, consequently, such regimes do not exist. In the time available, it was not possible to visit or contact all of the state or regional control agencies, so the evidence supporting this conclusion was derived from second visits to agencies visited during the Panel 2 study and to agencies known to have been working on mandatory maintenance regimes for some time. All of the statements are based on information furnished by the agencies during the spring and summer of 1974.

6.1 Background

The Panel 2 Report reviewed the situation which existed in the middle of 1972 with regard to mandatory enforcement of proper maintenance of cars (Ref. 1, pp. 88 to 93). This review pointed out that although the Act made it the responsibility of the states to operate such programs, the Act also gave certain responsibilities to the EPA and these had not been completed. The review also included discussion of the problems and delays which had been encountered in the furthest advanced program (New Jersey) and of the factors which appeared to make it impossible to institute a mandatory program quickly. At that time no mandatory program to enforce proper maintenance of all cars existed in any state or city. Actions which are illustrative of the lack of progress since that time are cited below.

6.2 Actions Regarding Enforcement of Maintenance Since June 1972

EPA has designated 19 metropolitan centers which must have mandatory inspection-maintenance programs as part of the implementation plans for 12 states. Among these are Chicago, New York, Los Angeles, and Washington, D.C.

New York State has not made any significant progress toward mandatory enforcement of proper maintenance since 1972. Although legal authority exists to add emissions inspection to the safety inspection done in licensed garages, new legislation would be required for either a state-controlled or a state-operated system. It is doubtful whether this legislation would pass. There are no funds for emissions inspection in the current budget and it is doubtful if New York will act without a large federal grant. Although the state implementation plan required a mandatory program in the New York metropolitan area no real action has been taken. A bill authorizing voluntary state certification of mechanics was vetoed by the governor last year.

New York City has the authority to enforce maintenance on vehicles for hire (taxicabs, etc.,) with regard to both safety and emissions. An inspection facility has been contructed, but there was opposition by the taxi owners and the mayor did not issue an order for inspection to start until months after the completion of the facility. The owners were not concerned about the safety features of the inspection, but they reportedly opposed the emissions inspection because they believed their mechanics were not trained to handle the problems.

Pennsylvania has the authority to enforce emissions-related maintenance but has not acted even though the implementation plan accepted by the EPA requires such a program in Pittsburgh and Philadelphia by May 1975. There is political opposition; in fact, there appears to be support from some officials to allow the removal of emissions-control devices.

Washington, D.C. has had broad powers to control air and other types of pollution since 1968 and regulations exist authorizing the inspection of vehicles for the deactivation of devices; this does not appear to be enforced strictly. Amendments now awaiting signature would expand this authority to cover mandatory enforcement of maintenance and certification

of mechanics and facilities. These will probably be signed, but enforcement will not start until 1976. The District is the one jurisdiction which has had clear authority for years and which does not seem to have encountered political opposition, yet the system has not been made operational in six years.

Arizona is operating prototype emissions-inspection facilities in two counties on a mandatory basis for publically owned vehicles and on a voluntary basis for privately owned cars. Arizona once had a vehicle safety inspection program and this law was repealed because of public and political pressure stemming from alleged graft and corruption in the service industry. Probably because of this experience, Arizona is proceeding cautiously.

California has recently passed legislation (SB 479) calling for the design of a pilot emissions-inspection system to be placed in operation in part of the South Coast Basin. The schedule calls for mandatory emissions inspection of all vehicles in the test area at time of registration beginning 1 January 1977. A recommendation is to be made by the end of 1974 as to whether this system should be extended to other parts of the state at some future time.

Chicago is operating an emissions-inspection program and the schedule made it mandatory for all cars in the city to have passed the inspection by 1 June 1974. Only about 30% compliance was achieved and the deadline has been postponed for a year. An attempt to obtain better compliance will be based on scheduling cars by license number. This program was opposed by the news media and by the auto clubs mainly as a result of carry-over from the alleged graft in the old safety inspection lanes. The implementation plan approved by EPA for Illinois specifies that no car registered in Cook County can get an Illinois license after May 1975 without having passed an emissions inspection. Cook County will have the

responsibility for these inspections in the area outside of the City of Chicago and they are moving slowly. The state government apparently plans no maintenance enforcement action in other areas of Illinois.

Colorado has studied the question and has plans for an idle emissions-inspection program which is scheduled to become fully operational in January 1977. They are moving slowly because of the political climate.

New Jersey is the only state with a mandatory inspection-maintenance regime in operation. The history of early opposition and delays is reviewed in the Panel 2 Report (Ref. 1, pp. 92 to 93), and when that report was written, mandatory maintenance with re-inspection was scheduled to start on 1 July 1973 after one year of emissions inspection without a requirement for compulsory maintenance and re-inspection. However, on 22 June 1973, a law was signed delaying mandatory compliance with the emissions standards until 1 February 1974 and since then the progressive tightening of standards has been delayed to 1 February 1975 and 1 February 1976 from 1 July 1974 and 1 July 1975. A public hearing was held on 11 June 1974 and opposition at that time caused some proposed new regulations, including standards for 1975 cars stricter than for 1974 models, not to be promulgated as scheduled. During the first two months (February and March 1974) of compulsory maintenance and re-inspection, about 11 of the cars failed the quite lenient standards on first inspection and one fourth of these failed re-inspection.

It is clear from the above illustrative examples that the most significant actions during the last two years in the area of enforcing proper maintenance have been further delays. It is also clear that regimes for enforcing maintenance do not exist and will not exist for a number of years at least, if the past is any guide. An evaluation of the probability of having such regimes in time for them to be a factor in the reduction of exhaust emissions must include a look at the reasons for the lack of progress. This will be done in Section 9.

7. PROBABILITY THAT THE 1975-76 CARS WILL MEET THE STANDARDS UNDER EXISTING MAINTENANCE CONDITIONS

This section presents the evidence and reasoning supporting Conclusion 4: The 1975-76 exhaust-emissions standards will not be met in actual use because the proper maintenance will not be performed. The margin by which they fail may be small. Following some introductory material, the discussion will be divided into five subsections; namely, maintenance required or recommended by the manufacturers, the past record as it applies to non-catalytic control systems, the past record as it applies to catalytic control systems, causes of oxidation-catalyst failure, and causes of NO_x control device failure.

7.1 Introduction

Three primary facts characterize the existing maintenance conditions:

- The service industry is adequate to maintain properly the 1975-76 cars (Section 5).
- Enforcement regimes to ensure proper maintenance and to prevent device deactivation do not exist (Section 6).
- Periodic tests to determine whether the oxidation catalyst is still active are not being included in the regular maintenance recommended by the manufacturers.

These three facts mean that the cars will not receive proper maintenance and that device deactivation will occur. Evaluation of the probability that 1975-76 cars will meet the standards then becomes a problem of estimating the emissions effects of less-than-adequate maintenance and inoperative control devices.

It should be emphasized that "meet the standards" has the precise meaning stated in Subsection 3.4 and that the conclusion that the 1975-76 cars will not meet the standards is based on a strict interpretation of that definition. Consequently, the conclusion should not be interpreted as meaning that the introduction of the 1975-76 cars will

not cause a significant reduction in automotive air pollution.

7.2 Maintenance Recommended Or Required by the Manufacturers

A survey of the functional tests and preventive maintenance recommended or required as a warranty condition by the manufacturers[5] showed that all of the needed tests and maintenance are included except two. The most important is a functional test to determine whether the catalyst is active. As will be seen below, detection and correction of inoperative catalytic systems are essential if the 1975-76 cars are to meet the standards. Consequently, a functional test for activity should be performed every time the car is in for service. Omission of such a test is hard to understand in view of its importance and in view of the inclusion of tests to determine whether the NO_x system is working. The second omitted item is an exhaust sampling port ahead of the catalyst so that engine malfunctions can be diagnosed with an infrared analyzer.

7.3 Non-Catalytic Control Systems

The past record of how well cars have met the applicable standards is the best indication of how closely the 1975-76 cars that will depend on non-catalytic emissions-control systems will meet the standards. The only exception will be the non-catalytic systems that will use unleaded gasoline, since they will have the advantage of less required maintenance on some important components.

The fact that cars during the last few years have not met the applicable standards in use has been proved by numerous determinations of the emissions of privately owned vehicles (see Ref. 1). The EPA and California Air Resources Board (ARB) surveillance programs are perhaps the best examples. The EPA announcement[18] on 26 June 1974 that as many as 1.4 million 1972 cars might be subject to recall because surveillance testing showed that they failed to meet standards is the most recent confirmation of this

fact. Similarly, the EPA announcement[19] on 27 February 1974 that exhaust-emissions controls had been disconnected or removed from 13% of the late-model cars inspected in the District of Columbia during the previous month and that evidence of possible tampering had been found in an additional 35% is clear evidence that device deactivation still occurs on a large scale. The EPA exhaust-emissions surveillance program for Fiscal Year 1972[20] shows that only 42% of the 1972 cars tested in St. Louis, Chicago, Houston and Washington, D.C. were meeting both the HC and CO standards, only 29% in Los Angeles and only 3% in Denver.

It should be noted that EPA was comparing the emissions from cars with an average mileage of about 15,000 with the standards that these vehicles are supposed to meet at 50,000 miles. When this fact is considered, the above compliance percentages indicate that maybe none of the 1972 cars will really meet the standards; i.e., at 50,000 miles.

Some people, in discussing the EPA surveillance results, have tried to paint an optimistic picture by pointing out that the average emissions from the cars in the four-city study only exceeded the standards by a small amount even though only 42% of them met the standards. This reasoning completely ignores the fact that the standards apply at 50,000 miles, not at 15,000; a classic example of the failure to understand the definition of the standards which was mentioned in Subsection 3.4.

The California ARB surveillance program dates back to December 1965 when the first tests were run on 1966 vehicles--the first ones controlled in California. The results of this extensive program first showed what the EPA surveillance testing is now demonstrating on a broader basis; namely that cars in use do not meet the applicable standards under present maintenance conditions.

A large amount of data has been accumulated, and two typical figures from the ARB "Statistical Evaluation of Surveillance Data" dated October 1973 are reproduced in Figure 7.3.[21] The standard shown for HC is applicable to 1972 and 1973 cars only, but the CO standard applies to all three years. A continually updated computer program is used to plot these curves from experimental data and to predict the performance of new models at extended mileage. This is why the curves extend to high mileage even for the newer cars. However, experimental data were available to 30,000 miles for the 1972 cars and to 20,000 miles for the 1973's. It is clear from these curves (and many more in ARB reports) that cars in use exceed the standards applicable at 50,000 miles even at comparatively low mileage, the same result as the one obtained by the EPA.

Since there has not been any significant change in the governmental activities for enforcing proper maintenance or preventing device deactivation, and since the service industry is still inadequate, the past record must be interpreted as meaning that the 1975-76 cars with control systems similar to the present ones (non-catalytic) will not meet the standards.

7.4 Past Record as It Applies to Catalytic Control Systems

The past record cannot be as directly applied to deciding whether the 1975-76 cars using catalytic converters will meet the standards. The past record does, however, offer clear evidence that proper maintenance is not performed under existing service-industry and enforcement conditions and that deactivation of control devices continues as a problem. The past record cannot be applied as directly because an active catalyst hides other defects and the maintenance needs are reduced by the use of unleaded gasoline. The certification and field-test results indicate that 1975-76 cars will meet the standards if the catalyst and the NO_x control system are both working. Consequently, to determine whether 1975-76 cars with such systems will meet the standards, it is necessary to estimate the probabilities of failure of the two systems and the emissions effects of such failures.

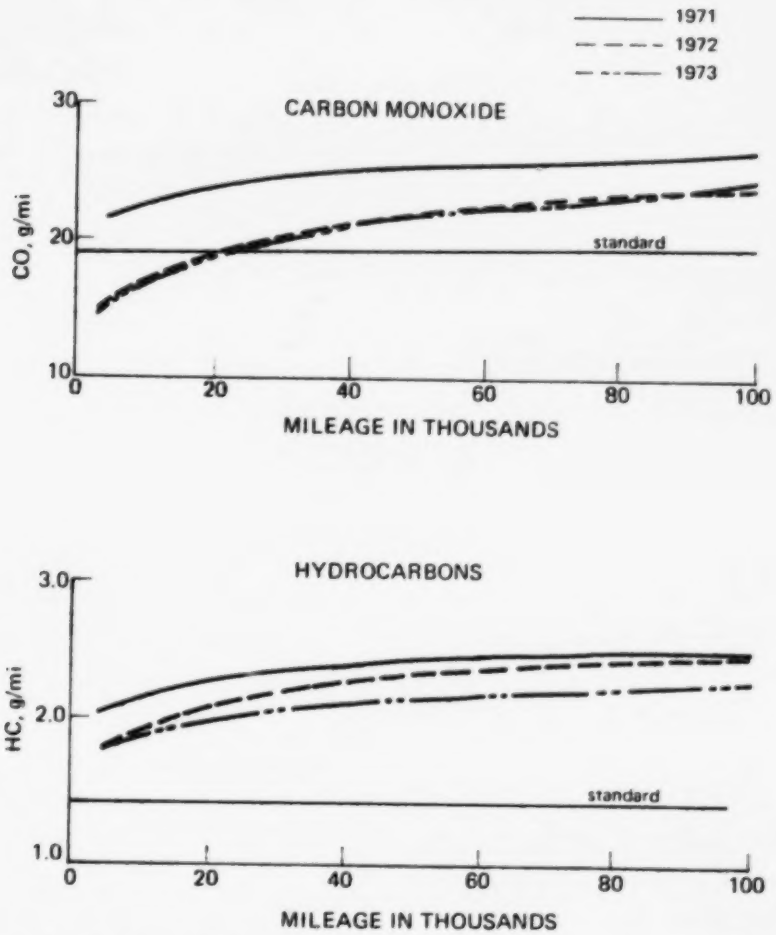


FIGURE 7.1 Exhaust Emissions vs. Mileage--1971, 1972 and 1973 Models, California Population, All Tests Hot Start

REF. 21

7.5 Causes of Oxidation Catalyst Failure

Even though the results of the certification and field tests (see Subsections 4.2 and 4.3) of catalytic systems indicate that these systems will meet the standards, if properly maintained, there were instances of catalytic converter failures. The number of failures in the 50,000-mile durability fleets[5] appears to be quite small (about 3 or 4 in 200 cars), but it is difficult to obtain definite figures. It is clear that the percentage of failures in the field tests was higher, in line with the commonly held, but not-proved, belief that actual use in the customers' hands will be harder on the catalysts than the Durability Driving Cycle. The reasons advanced for this belief are poorer control of the fuel quality and about 700 times as many starts and stops (heat cycles) in 50,000 miles. Whether the additional heat cycles had an effect is not known, but the field-test vehicles did experience fuel problems similar to the ones that can be expected in general usage.

The taxicab fleets equipped with GM under-floor catalytic converters (see Subsection 4.3.1) had four catastrophic converter failures[10] in a total of about 100 vehicles. These failures occurred in the Los Angeles and Phoenix fleets (20 cars each) and were all attributed to engine misfire. Fleets were operated in Denver, Los Angeles, Phoenix and Pontiac and the last three fleets all experienced fuel problems which could easily reoccur in the "real world". The Los Angeles fleet experienced severe spark-plug fouling when fueled with gasoline containing twice the normal amount of detergent. The Phoenix fleet had even more severe spark-plug fouling which was traced to gasoline containing large quantities of higher-boiling components. The distillation curve from 30% to 80% evaporated averaged 30 ^{o}F higher than specifications; the supplier had used heavier stocks apparently because of the fuel shortage. Both of these cases of spark-plug fouling would probably have led to more cases of

complete failure, if they had not been discovered and corrected because of good maintenance supervision. A batch of gasoline with unusually high phosphorus content completely deactivated the catalysts in the Pontiac test and the test had to be restarted.

The 450-car Ford fleet (see Subsection 4.3.2) had 17 catalytic converter failures[11] of which 15 were melting of the substrate and 2 were flange leaks. The substrate melting was attributed to total ignition loss under road load in each case and the causes are being corrected in 1975 production vehicles and the flange design has been improved. Nevertheless, these represent the types of failure that can occur as the result of improper maintenance. This fleet also experienced some instances of fuel with too high a lead content, but none of the exposures continued for sufficient time to deactivate any of the catalysts completely. This experience confirmed the fact that catalysts now being used can recover almost completely from infrequent and short-term lead exposure.

The totality of experience during the development of catalytic control systems leads to the following list of field conditions which probably would cause catalyst failures.

- Complete ignition failure at moderate to high speeds.
- Misfires caused by ignition failures.
- Running out of gasoline at moderate to high speeds.
- Severe dieseling.
- Stuck choke.
- Failure of coasting protection control.
- Fuel which causes spark-plug fouling.
- Fuel which directly poisons the catalyst.

All of these possible reasons for catalyst failure were cited by the manufacturers as things which had occurred.

An estimate based on field experience with the current engines, adjusted downward to allow for improved components and the use of unleaded fuel, indicates that engine malfunctions that could lead to catalyst failures would be expected to occur in 3% to 4% of the car population distributed from zero to 50,000 miles and in a somewhat higher percentage of the vehicles which have reached 50,000 miles. It is, of course, not known to what extent each engine malfunction will lead to complete catalyst failure or only to partial deterioration. It is also not known what effect a combination of malfunctions or partial malfunctions will have. For example, intermittent lean misfires and spark-plug misfires may work together to overheat the catalyst without causing a customer driveability complaint. The combination of a partially stuck choke and plugged air cleaner could also overheat the catalyst. Such engine malfunctions may cause a continual overheating of the catalyst which results in loss of active surface area due to shrinkage of catalyst substrates and agglomeration of platinum (see Ref. 22).

One of the biggest problems will be spark-plug wires. Field experience has shown that mechanics often damage these wires when they replace spark plugs or remove spark plugs for diagnostic purposes. When the wires deteriorate with heat they become brittle and are easily broken when removed. The auto manufacturers have helped to reduce this problem by improving the thermal stability of the wires. These changes will help minimize this problem, but the problem will continue to exist until it is eliminated by mechanic training.

Running out of gasoline at moderate to high speeds is also a problem,[5] since this will usually destroy the catalyst. The American Automobile Association, based on projection of their emergency road service to a national figure, indicated in a 10 June 1974 news release that approximately 2.9×10^6 cars were serviced beside the road due to running out of gasoline and another 2.1×10^6 cars received emergency road service

because of inoperative fuel systems during 1973. These two estimates taken together indicate that about 5% of the emergency road service was to vehicles with engines not receiving gasoline. Both of these types of failure would almost always occur while the car is being driven, but there is no way of knowing what percentage will occur at moderate to high speeds. The final report on a study made by Traffic Safety Corp. of Palo Alto, CA for the U.S. Department of Transportation under Contract No. DOT-HS-261-3-771 indicates that a fairly large percentage of the cars disabled in highway driving are disabled for reasons which might lead to catalyst failure. Through the cooperation of the California Highway Patrol the owners of 7,000 vehicles found disabled beside highways in the San Francisco Bay Area were requested to complete a questionnaire on the cause. Replies were received from 2,309 and 21.74% had run out of gas, 6.54% had had fuel-system failure, and 1.65% had had ignition failure. These data show about 30% of the cars disabled during highway driving (moderate to high speed) are disabled for reasons known to cause catalyst failure. However, these data should be interpreted cautiously because it is not known what percentage of all the cars being driven in the Bay Area at that time is represented by the 2,309 in the survey.

Spark-plug fouling by substandard gasoline or by abnormal oil consumption has already been discussed. A more frequent occurrence, particularly during the next year or two, will be the direct poisoning of the catalyst by the use of fuel containing lead or phosphorus. Phosphorus is a severe poison and instances of such poisoning will undoubtedly occur, but the frequency should be less than that for lead, since it is only added to counteract some of the effect of lead on engine deposits. Present evidence indicates that the reduction in catalyst activity caused by the use of leaded fuel is twofold. The immediate sharp drop in activity is apparently a chemical effect connected with the bromine and chlorine scavengers. Considerable data show that this initial drop in activity is reversible, if the leaded fuel is used for only a

short time and is followed by the use of unleaded fuel. However, there is another permanent effect; namely, the coating of the active sites by the accumulation of lead. This can occur to the point where catalyst activity is seriously reduced or destroyed either by the use of three to five tankfulls of leaded fuel or by the continual use of gasoline containing small amounts of lead.

There are no hard data to show what percentage of the catalysts will be inactive because of the combination of the above possible causes. Optimistically, proper maintenance might hold the percentage at 5% or a little below in the car population distributed from zero to 50,000 miles. However, if the failures are not detected and corrected soon after they occur, 10% inactive catalysts in the car population is a more probable figure. Both of these estimates will be higher for the cars which have been driven 50,000 miles, the point at which the standards apply. One manufacturer of small displacement automobiles felt that it could be as high as 25% inactive catalysts until more field experience has been accumulated (see Ref. 22, Section IV).

7.6 Causes of NO_x Control System Failures

EGR system failure should be much lower than on pre-1974 model vehicles because the use of unleaded fuel practically eliminates deposits.[5] This eliminates common failures such as the plugging of the valve body, lines and connectors with leaded deposits. Only a slight carbonaeous deposit forms with unleaded fuels over the life of the engine.[5] The manufacturers have extended the recommended intervals for cleaning the EGR system from 12,000 miles to greater than 50,000 miles; i.e., it is no longer part of the warranty maintenance.

Other failure modes of the EGR system such as vacuum-line leaks, servo-actuation mechanism malfunction, servo-vacuum diaphragm leakage,

or exhaust-gas pressure diaphragm malfunction should not occur more frequently than a fraction of a percent in the entire car population. The secondary components of the control system, spark retard and A/F ratio, should also not contribute a significant percentage of failures. Consequently, since the deterioration factor for NO_x control is about 1.0, it would seem that the 1975-1976 cars should meet the standards. However, this assumes that the EGR systems are not purposely disconnected by the owners.

This assumption is not valid for many parts of the country. The recent surveillance[19] of vehicles by the EPA in the Washington, D.C. area (Subsection 7.3) showed that 13% of the emissions-control systems were deactivated. It must therefore be concluded that the 1975-76 vehicles will have a significant percentage of inoperative NO_x control systems in the absence of effective regulatory action.

The above refers to NO_x control systems based on EGR on vehicles which are forced to use unleaded gasoline because the HC and CO emissions are controlled with an oxidation catalyst. There will be some cars without an oxidation catalyst which are manufactured so as to restrict the fuel to unleaded gasoline; the above comments are also valid for these. The fact that cars with control systems essentially like the ones on 1974 vehicles (non-catalytic) will have essentially the same maintenance problems and record as present cars has already been pointed out in Subsection 7.3. These vehicles will not receive the benefits of using unleaded fuel and the EGR systems will need the present maintenance intervals to remain operative.

On the basis of the recently established standards, catalysts will not be used to control NO_x emissions until the 1978 model year. Until the causes for deterioration or deactivation of reducing or three-way catalysts are better understood, the only reasonable assumption is that these catalysts in 1978 will be approximately as reliable and durable as

the oxidation catalysts are now.

7.7 Summary

The 1975-76 cars will not meet the standards because they will not receive proper maintenance and intentional deactivation of control devices will not be prevented under existing conditions. The cars with non-catalytic control systems will exceed the standards by a fairly large percentage judged on the basis of the performance of present cars with similar control systems. The cars with catalytic control systems will have enough inoperative catalytic converters and NO_x control systems to cause the average emissions to exceed the standards.

The discussion in Section 8 on the effect of inoperative devices on emissions uses the concept of "untreated exhaust"; i.e., any exhaust emitted for any reason without passing through a properly functioning control device. The estimates in Tables 8.1, 8.2, and 8.3 indicate that the 1975-76 cars with catalytic converters will probably not exceed the CO standard by a significant amount and that they will probably exceed the HC and NO_x standards by only about 10%. These are only approximate estimates and are based on the indication from the discussion in this Section 7 that the cars at 50,000 miles, under present maintenance conditions, will have about 15% to 20% untreated exhaust. The tables referred to were constructed to apply to cars which had reached 50,000 miles. The percentage of untreated exhaust in the entire population distributed from zero to 50,000 miles will probably be lower, maybe 10% to 15%, but this does not change the above comment (see Subsection 8.1). Reference above was to the federal standards; the same percentage of untreated exhaust would mean that the California standards were exceeded by 15% to 35% depending upon the pollutant.

The primary reasons why the cars will not receive proper maintenance are that governmental programs for enforcing proper maintenance will not

exist and that the service industry is inadequate. Intentional deactivation will also occur because of the absence of enforcement programs. A contributing reason is the failure of the manufacturers to include a test for catalyst activity in the recommended maintenance.

8. EFFECT OF UNTREATED EXHAUST ON AVERAGE EMISSIONS

This section presents the evidence and reasoning supporting Conclusion 5: Proper maintenance becomes more important as emissions standards become stricter, because untreated exhaust increases the percentage by which actual emissions exceed allowed emissions more rapidly than linearly as the required efficiency of control devices increases. The term "untreated exhaust" is used to describe any exhaust which is emitted from a car without having passed through a properly functioning control device. This untreated exhaust can be the result of failed control devices, intentionally deactivated control devices, exhaust leaking to the atmosphere before passing through a control device, control devices whose average efficiency is below the required value, or any combination of these causes.

The discussion is in two parts; namely, the rate at which average emissions increase as a function of the percentage of untreated exhaust and the required efficiency of the control devices, and the application of this concept in terms of present vehicles and standards.

8.1 Average Emissions as a Function of the Percentage of Untreated Exhaust and the Required Efficiency of the Control Devices

It is possible to investigate the dependence of average emissions on the percentage of untreated exhaust, the stringency of the standards, and the deterioration of emissions control from zero to 50,000 miles without any reference to specific standards or levels of contaminants. Since this approach focuses attention on these important relationships without introducing unnecessary assumptions, it will be used.

Assume a Group A of cars which have a mean emission, E_a, of some contaminant and a Group B of cars with mean emission, E_b. Form a new Group C of cars by replacing a fraction, x, of the cars in Group A

with an equal number from Group B. The mean emissions, E_c, of the new Group C will then be

$$E_c = xE_b + (1 - x)E_a$$

or

$$E_c = E_a + xE_a\ (r - 1) \qquad (1)$$

where

$$r = E_b/E_a$$

It was implicitly assumed in arriving at equation (1) that the members of Group A which were replaced had a mean emission of E_a and that the members of Group B used as replacements had a mean emission of E_b. If this condition is not met, equation (1) is not valid. It is also important that the values of E_a and E_b used in equation (1) be the actual mean values of the Groups A and B as defined.

Equation (1) is completely general and does not depend on any assumptions about standards, emissions levels, safety factors, deterioration rates, or the like. In fact, it is so general that the groups do not need to be cars and the property averaged does not need to be emissions. However, for present purposes, the application of equation (1) will be restricted by further defining Groups A and B. Assume that all of the cars in Croup A are ones in which the exhaust is treated by properly functioning control devices and that Group A just meets the standard; i.e., E_a equals the standard. Further assume that the cars in Group B are ones from which the exhaust is emitted without treatment by a properly functioning control device. With these definitions, 100x is the percentage of untreated exhaust, 100 (1 - 1/r) is the percent reduction which a control device must achieve to meet the standard, and 100 (E_c/E_a - 1) is the percentage by which the group with 100x percentage of untreated exhaust exceeds the standard. Figure 8.1 shows these two quantities plotted against each other for values of 'x' of 0.05, 0.10, and 0.20.

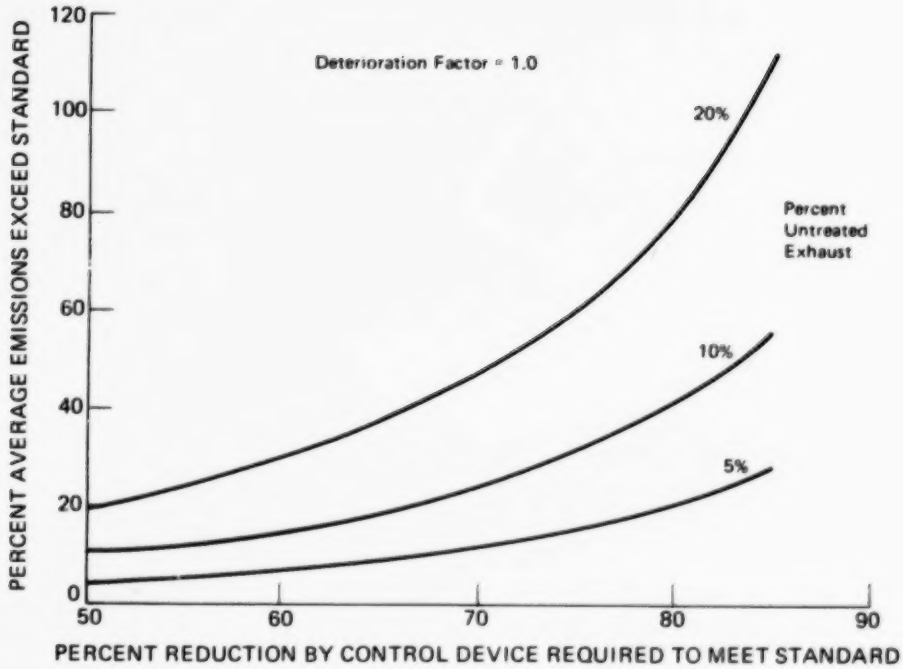

Deterioration Factor = 1.0
20%
10%
5%
Percent
Untreated
Exhaust
PERCENT AVERAGE EMISSIONS EXCEED STANDARD
120
100
80
60
40
20
0
50
60
70
80
90
PERCENT REDUCTION BY CONTROL DEVICE REQUIRED TO MEET STANDARD

FIGURE 8.1

These curves show that the percentage by which the average emissions exceed the standard increases linearly with increased percentage of untreated exhaust, as expected, if the required percentage reduction by the control device remains constant. However, the percentage by which the average emissions exceed the standard increases more rapidly than linearly with an increase in required reduction by the control device, at a constant percentage of untreated exhaust. This means that the effect of untreated exhaust increases more rapidly than linearly with an increase in the stringency of the standard. As an example, if 'y' is the standard and it takes 60% reduction in the raw exhaust concentration to meet the standard, 10% of untreated exhaust causes the average emissions to exceed the standard by 15%. If the standard becomes 'y/2', it will require an 80% reduction of the raw exhaust concentration to meet the standard and 10% untreated exhaust will cause the average emissions to exceed the standard by 40%.

Since the standards are exhaust levels which must be met at 50,000 miles, the curves in Figure 8.1 really refer to a group of cars which have reached 50,000 miles and are emitting the indicated percentages of untreated exhaust. On this basis, the abscissa axis should be labeled "Percent Reduction Required at 50,000 Miles by the Control Device to Meet Standard". This has not been done because these curves also show the percentage by which the average emissions from a group of cars distributed in mileage from zero to 50,000 miles would exceed the standard with the indicated percentages of untreated exhaust <u>if the deterioration factor is unity</u>. Another phrasing may make this limitation clearer: A deterioration factor of unity means that the average emissions E_a, of a Group A of cars which will just meet the standard at 50,000 miles do not increase in going from zero to 50,000 miles.

Deterioration factors greater than unity are probable for some pollutants, so the effect of the deterioration factor should be investigated

further. A deterioration factor greater than one will cause the average emissions from a group of cars distributed from zero to 50,000 miles to exceed the applicable standard by a larger percentage than shown by Figure 8.1, for the same percentage of untreated exhaust and the same required reduction at 50,000 miles. To illustrate, Group A is defined as a group of cars all with properly functioning control devices, evenly distributed from zero to 50,000 miles, and whose average emissions increase linearly from one half the standard at zero miles to exactly the standard at 50,000 miles. This then is a group with a deterioration factor of two which will just comply with the standard if there is no untreated exhaust.

There are several ways of stating the reason why this deterioration factor will cause the average emissions from this group to exceed the applicable standard by more than a group with a deterioration factor of one, for the same amount of untreated exhaust and the same required reduction at 50,000 miles. The value of E_a is smaller for this group, so 'r' in equation (1) is larger; E_a for this group is only three-fourths of the E_a for a group which is identical in all respects except that it has a deterioration factor of one. Put another way, the replacement of cars which are emitting significantly less than the standard (cars at low mileage) with cars emitting raw exhaust will have a larger effect on the group average than replacing cars which are emitting exactly the average (all the Group A cars when the deterioration factor is one). Put still another way, the standard which the average of the group with a deterioration factor of two should meet is three-fourths of the real standard where the real standard is the one which by definition this group meets at 50,000 miles. And a final way to look at it, if it takes a 50% reduction in raw exhaust concentration to equal the average emissions of the cars in this group which have just reached 50,000 miles, it will take a 62.5% reduction in raw exhaust to equal the average emissions of the entire group distributed evenly from zero to 50,000 miles.

Figure 8.2 contains curves which show the percentage by which the average emissions from the group defined above, with a deterioration factor of two, exceed the applicable standard for 5%, 10%, and 20% untreated exhaust. These curves are valid only for the defined group and a deterioration factor of two, and are included to illustrate the effect of a deterioration factor. Figure 8.1 is valid for all groups which have a deterioration factor of one and for all groups which are not distributed across mileage; i.e., for all groups at 50,000 miles where the legal standards are applicable.

8.2 Effect of Untreated Exhaust on Probability of Meeting Present and Future Standards

To interpret the above basic relationships in terms of the probability of meeting present and future standards, it is necessary to select some values for the average concentrations of the three principal pollutants in untreated (raw engine) exhaust. These values have been selected as 5.0 g/mi NO_x, 2.5 g/mi HC, and 18.0 g/mi CO on the basis of data furnished by the manufacturers[5] about the composition of exhaust from different size engines and an estimate of the probable 1975 sales distribution. These values are probably correct to $\pm$ 20% to 25% which is sufficient for the purpose.

It has also been assumed that the average car will just meet the standards at 50,000 miles if all control devices are working properly. In view of the EPA and ARB surveillance data cited in Subsection 7.3, this assumption is probably unduly optimistic and it might be more reasonable to assume that the average car will fail to meet the standards at 50,000 miles by some specified percentage. Actually there are opposing forces which should cause the manufacturers to produce cars which just meet the standards. Sanctions which the EPA can impose make it unwise to fail to meet the standards by a significant amount, and the need to

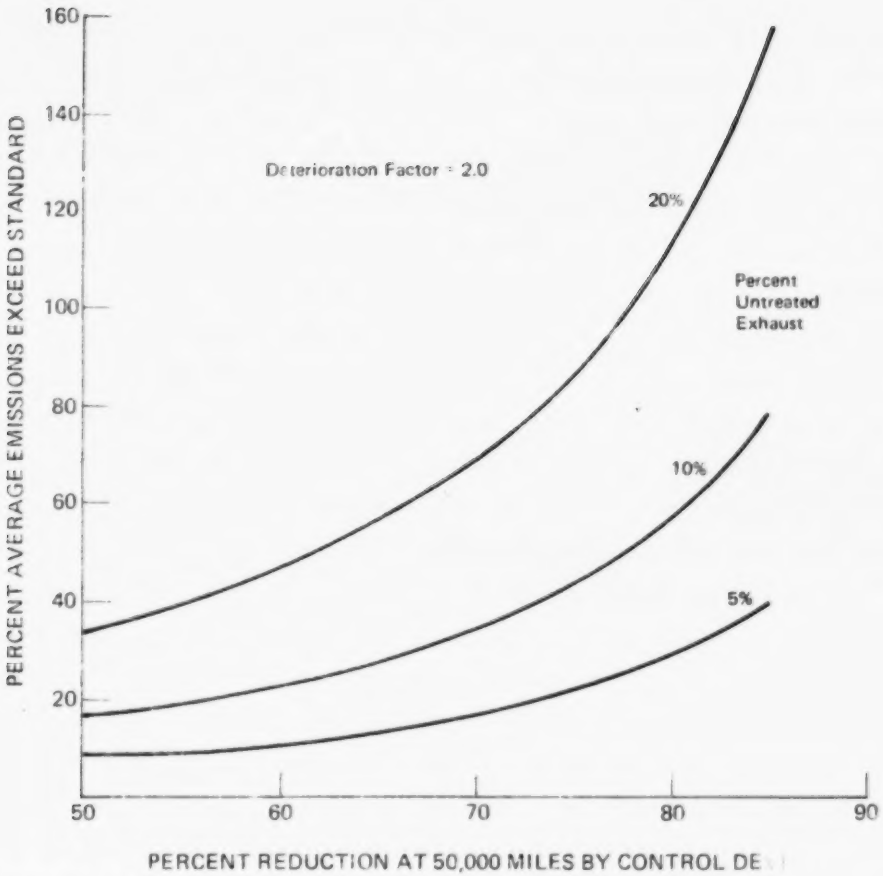

160
140
120
100
80
60
40
20
PERCENT AVERAGE EMISSIONS EXCEED STANDARD
Deterioration Factor = 2.0
20%
Percent
Untreated
Exhaust
10%
5%
50
60
70
80
90
PERCENT REDUCTION AT 50,000 MILES BY CONTROL DE

FIGURE 8.2

maximize both gasoline mileage and profit makes it unwise to control the emissions more strictly than is required. Some individuals have even suggested that the manufacturers will include a safety factor and produce cars whose average emissions are below the standards at 50,000 miles. They point to the fact that some of the prototypes used for certification testing were below the standards at 50,000 miles as support for this position. This is an unjustified extrapolation of data obtained for an entirely different purpose.

In spite of the above arguments supporting the reasonableness of assuming that the standards will just be met at 50,000 miles, there is a more important reason for this choice. Any attempt to pick exactly how much the cars will exceed or be under the standards implies that the technique described in the last subsection can be used to calculate the probable emissions from 1975-76 cars after they have gone 50,000 miles. Fostering such an implication in the mind of the reader would constitute deception with the present lack of reliable data to use in equation (1). The technique can only be used to indicate the magnitude of the increase in average emissions caused by untreated exhaust; this is the only purpose intended in this report and the reader is cautioned against interpreting the numbers listed in the following tables as probable emissions of 1975-76 cars at 50,000 miles. Since attempting to select the exact emissions at 50,000 miles is unwarranted, the assumption, which does not require any subjective judgment, and which does not imply an exactness which does not exist, is that the average emissions will just meet the standards.

On the basis of this assumption and the selected concentrations of HC, CO and NO_x in raw exhaust, the magnitude of the effect of various percentages of untreated exhaust on the average emissions of cars <u>at 50,000 miles</u> are shown in Tables 8.1, 8.2, and 8.3 for each of the standards specified by Public Law 93-319 (see Subsection 3.4).

TABLE 8.1

MAGNITUDE OF UNTREATED EXHAUST EFFECT ON HC EMISSIONS

Percent Untreated Exhaust	Percent Average Emissions Exceed Stated Standards			
	75-76 Fed. 1.5 g/mi	75-76 Calif. 0.9 g/mi	77-78 0.41 g/mi*	0.41 g/mi*
2.5	1.5	4.5	13	6
5	3	9	25	12
10	7	18	51	23
15	10	27	76	35
20	13	36	102	47
25	17	44	127	58
30	20	53	153	70

*If the present raw exhaust content of HC remains unchanged, the catalyst would need to oxidize 83.6% of the HC at 50,000 miles to meet the 1977-78 standard. This seems unlikely without a catalyst change. Consequently, a second calculation was made on the assumption that the catalyst needed to make only a 70% reduction to meet the standard; column 4 is 83.6% reduction and column 5 is 70%.

TABLE 8.2

MAGNITUDE OF UNTREATED EXHAUST EFFECT ON CO EMISSIONS

Percent Untreated Exhaust	Percent Average Emissions Exceed Stated Standards			
	75-76 Fed. 15 g/mi	75-76 Calif. 9 g/mi	77-78 3.4 g/mi*	3.4 g/mi*
2.5	0.5	2.5	11	6
5	1	5	21	12
10	2	10	43	23
15	3	15	64	35
20	4	20	86	47
25	5	25	107	58
30	6	30	129	70

*If the present raw engine content of CO remains unchanged, the catalyst would need to reduce the CO by 81% at 50,000 miles to meet the 1977-78 standard. This seems unlikely without a catalyst change. Consequently, another calculation was made on the assumption of a required reduction of 70%; column 4 is 81% reduction and column 5 is 70%.

TABLE 8.3

MAGNITUDE OF UNTREATED EXHAUST EFFECT ON NO_x EMISSIONS

Percent Untreated Exhaust	Percent Average Emissions Exceed Stated Standards			
	75-76 Fed. 3.1 g/mi	75-76 Calif. 2.0 g/mi	78 0.4 g/mi*	0.4 g/mi*
2.5	1.5	4	29	10
5	3	8	58	20
10	6	15	115	40
15	9	23	173	60
20	12	30	230	80
25	15	38	288	100
30	18	45	345	120

*Column 4 has been calculated as if raw exhaust from a 1975-76 engine were being emitted; i.e., both the EGR and the reducing catalyst are inoperative. Column 5 has been calculated to represent the case where the EGR is still operative, but the catalyst is not. The term "three-way catalyst" can be substituted for "reducing catalyst" in the above without changing the meaning.

The numbers in these tables should be interpreted cautiously. In particular, they should not be viewed as calculations of probable emissions from 1975-76 cars after 50,000 miles. They should be viewed only as estimates of the sensitivity of average emissions to untreated exhaust and the stringency of the standards. It is clear that the impact of untreated exhaust increases rapidly as the standards become more stringent; the increase is actually so rapid that a reduction in the pollutant concentrations in raw exhaust may be required to meet the 1977-78 standards. The impact of 15% untreated exhaust is not great at the level of the federal 1975-76 standards, but the impact is already definite and significant at the level of the 1975-76 California standards.

9. IMPACT OF POLITICAL ACTIONS AND SOCIAL ATTITUDES

This section presents the evidence and reasoning supporting Conclusion 6: The absence of regimes for ensuring proper maintenance and the present state of the service industry are both the results of social and political attitudes and are not the results of technical limitations.

Discussion of this subject requires reference to political actions which have delayed mandatory programs for ensuring the proper maintenance of cars. Citation of these political actions or reference to the social attitudes which influenced the actions should not be construed as expressing either approval or disapproval of the actions or attitudes. These actions and attitudes are, however, the most important items influencing the probability of the 1975-76 cars meeting the standards, and must for this reason be included. As stated earlier (Section 4) the 1975-76 cars are technically capable of meeting the standards and the primary reasons (Subsection 7.7) why they will not are the absence of regimes to enforce proper maintenance and the inadequacies of the service industry. Both of these are the results of social and political attitudes.

Political actions and social attitudes will be discussed as they apply to regimes for enforcing proper maintenance and to upgrading the service industry.

9.1 Regimes for Enforcing Proper Maintenance

It is clear from the discussion in Section 6 that the most significant actions in the area of enforcing proper maintenance during the last two years have been further delays. Any evaluation of the probability of having regimes to ensure proper maintenance must include a look at the reasons for this lack of progress. It would be naive to believe that the political

actions which have either opposed or delayed programs to enforce proper maintenance were capricious. Instead they must be accepted as true reflections of underlying social attitudes and beliefs. The American tradition has been to oppose all governmental control until it is proved necessary and this undoubtedly explains some of the opposition to mandatory maintenance and to the licensing of mechanics (see Section 9.2). The phrase "until it is proved necessary" leads to another underlying belief or, rather, doubt. There are still large segments of the population who doubt either that such programs are really needed, or that such programs would do much good, or that air pollution is a serious problem in their area.

There are also indications that some state officials hesitate to enter the quagmire created by the interplay of a state mandatory maintenance program and the individual car warranty provision of the Clean Air Act (see Section 207(b) of the Act and pp. 80 to 88 of Ref. 1). Since this provision of the Act contributes nothing to the achievement of the basic objective--reduction of the automotive contribution to air pollution--and since creation of regimes to enforce maintenance would be aided by its elimination, its repeal should be seriously considered.

Another very basic social hurdle is the general failure to realize that control of automotive air pollution must be paid for either in inconvenience or money or both.

An attitude of overriding importance is the almost universal distrust of mechanics. The existence of this feeling probably makes impossible the use of the only enforcement regime which could be instituted in less than five years. This will be discussed more in Subsection 9.2

9.2 Social Attitudes And the Upgrading of the Service Industry

A sufficient number of competent mechanics is needed for any mandatory maintenance regime. At present, there is a shortage of well-trained mechanics and there are deficiencies in the service facilities. A definite contributory cause is probably the public's low regard for mechanics and the service industry. The image which the industry has is neither conducive to having the public trust it with an important role in air pollution control nor conducive to attracting good new people. There is an almost universal distrust of mechanics and it is not confined to the United States, although it is definitely less in Japan[16] and Canada[17] where all mechanics are licensed and controlled by the government.

This situation may be alleviated by the present NIASE program of certifying competent mechanics (Subsection 5.5). The program could become autocatalytic, since an increase in the status for the certified mechanic would encourage others to improve their training. This, in turn, would begin to dispel some of the distrust, and the improved public image would probably attract more competent people. If the voluntary program continues to gain momentum, government licensing may not be required although it would help to dispel public mistrust and add motivation. The Japanese experience seems to indicate that licensing of mechanics supplies the needed motivation not only by enforcing a level of competence but also by establishing a certain degree of recognition for the trade. As noted above, licensing is a prerequisite for the regime of mandatory maintenance which could be placed in operation the soonest (Section 12).

10. MAINTENANCE IMPACT OF UNLEADED FUEL

This section presents the evidence and reasoning supporting Conclusion 7: The use of unleaded fuel will materially reduce the maintenance which a vehicle requires.

The absence of lead from the fuel results in the following maintenance advantages:[5,23]

- EGR valves require no service for 50,000 miles--no deposits.
- Spark-plug life is about doubled.
- The required interval for service of the heat-riser valve is extended by a factor of 4 or 5.
- HC and NO_x exhaust emissions from the engine (before any catalytic treatment) are lower by about 0.75 g/mi.

There are, of course, other advantages resulting from the use of unleaded fuel, but the ones above are the principal ones which influence the feasibility of meeting the emissions standards under the present inadequate maintenance conditions. It is interesting to note that at least one manufacturing firm is sufficiently convinced of the advantages of unleaded fuel that all of its cars in 1975 will be designed to accept only unleaded fuel,[23] including those models which will use non-catalytic control systems.

11. DURABILITY IMPROVEMENTS IN EMISSIONS-RELATED COMPONENTS

This section presents the evidence and reasoning supporting Conclusion 8: The 1975-1976 cars will probably come closer to meeting the standards than ones manufactured in the last few years, and this is particularly true for those using catalytic control systems.

The advantages of using unleaded fuel have been reviewed in Section 10 and these are, with some exceptions, advantages connected with the use of catalytic control systems. The catalytic control systems also have the advantages that an active catalyst will correct for considerable engine maladjustment, even some amount of misfire. Catalytic control systems have another peculiar but real advantage. Use of the catalyst permits the calibration of the engine for better performance and this reduces the incentive to deactivate control devices or alter engine adjustments to improve performance.

Ignition systems and fuel-system components have also been improved principally to help prevent either ignition or lean misfires that could lead to catastrophic failure of the catalyst. However, these changes should also reduce the maintenance required by the cars using non-catalytic controls and hence improve their ability to meet standards under the present maintenance conditions. These improvements include:[5]

- Electronic ignition systems that eliminate the rubbing-block-type breaker points in the distributor. This minimizes point failure and changes in spark timing.
- High tension ignition wires and connectors with greater thermal resistance. This will reduce breakage.
- Ignition systems with greater tolerance to water.
- In many cases, ignition systems with higher spark energy and larger spark-plug gaps. This results in longer spark-plug life.
- Fuel pumps with greater reliability and life.

12. POSSIBLE REGIMES FOR ENSURING PROPER MAINTENANCE

This section presents the evidence and reasoning supporting Conclusion 9: It is possible to hypothesize regimes for ensuring proper maintenance, but it is impossible to implement any of them in a significant number of states until after 1980 at the earliest.

Even though state action on regimes to ensure proper maintenance has been delayed (Section 6) and the service industry is inadequate (Section 5), it is valuable to examine the design of possible mandatory maintenance regimes. This examination should show whether these deficiencies can be circumvented or eliminated and whether there is a best regime on the basis of either effort or time to put into operation. The discussion will cover criteria and common characteristics, classification by type, some comparison of the three general types, and some requirements for the maintenance of 1975-76 cars.

12.1 Criteria and Common Characteristics

Any regime should be mandatory for all cars and enforcement must be a governmental responsibility. A system based on voluntary compliance would not accomplish the purpose or be socially acceptable. Emissions from cars operating under only partial enforcement would exceed the standards, and basing necessary social actions on an appeal to conscience just rewards those without conscience. The need for enforcement is common to all types, although the mechanism may vary.

Any regime for ensuring proper maintenance requires a sufficient number of competent mechanics, and ensuring competence is again a governmental responsibility. Detecting a car which has not been properly maintained or which is emitting over the standards does not by itself do anything to reduce emissions. Further action is needed and that action is adjustment or repair by a competent mechanic. The degree of competence required may be different for different regimes, but the

need for ensuring competence is common. A combination of licensing mechanics on the basis of skill tests and some surveillance of performance is probably the most viable approach.

The need for governmental responsibility for enforcing compliance and for ensuring competent mechanical work means that all regimes for ensuring meeting the standards require social and political acceptance of the necessity to control automotive emissions to the specified levels. In other terms, the public must be willing to accept the cost in time, money and inconvenience. This may require a fundamental change in the present social and political climate; mutual coercion, mutually agreed upon, for mutual benefit must be accepted.

The ideal regime would be equally applicable to new and existing cars. It is not clear that the ones now being considered for existing cars are the best for new cars and these are the most important since they represent a rapidly increasing fraction of the total.

Any regime should ensure performance of the proper maintenance. The engineering design of the class and the certification of the class for sale were both based on proper maintenance.

All of the possible types of regimes have in common the fact that it is impossible to prove that any of them will ensure meeting the standards It has also not been proved that any of these regimes is a more cost-effective method of reducing the pollution burden than other possible approaches (see Subsection 3.3).

12.2 Types of Regimes

There has been a tendency to classify maintenance regimes on the basis of where the work is done rather than on the basic approach used. This has confused attempts at classification and created a terminology

which does not describe real differences. For example, the term "inspection system" has been commonly used to mean state-operated or franchised inspection lanes in contrast to work done by the service industry. The common term "inspection/maintenance" has been used to signify inspection in state lanes and maintenance by the service industry. The term "mandatory maintenance" usually indicates a system based in garages without an inspection step. As noted above, any regime requires adjustment or repair by a mechanic, and any action by a mechanic must be preceded by some type of inspection or diagnostic step. Doing certain parts of the work one place or another may be preferable, but it does not change the work which is required and it does not form a logical basis for classification.

A classification which appears to describe real differences and which is independent of work location is:

- Functional inspection, diagnosis, repair and maintenance of all cars (including preventive maintenance) at specified intervals in either time or mileage.
- Repair or adjustment of only those cars found to be exceeding predetermined emissions standards.
- Manufacture of cars which will force the owner to repair or adjust any inoperative emissions controls.

12.3 Type I - Functional Inspection, Diagnosis, Repair and Maintenance of All Cars at Specified Intervals

This regime includes:

- Functional inspection and testing to determine whether specified components are operating properly;
- Functional inspection and testing to determine, if possible, any indications of near-term failure of critical components;

- Diagnosis of the causes of improper operation;
- Repair or adjustment of improperly operating components;
- Indicated preventive maintenance including manufacturer's specified maintenance;
- Documentation both for the control of the operation and for enforcement. This would probably be a checklist for control with indication of the action taken on each item for enforcement.

This system has the following characteristics:

- Is mandatory for all cars;
- Ensures proper maintenance, both that specified by the manufacturer and preventive;
- Requires only competent, controlled mechanics, not new construction or technical advances;
- Equally applicable to new and existing cars;
- Safety items are easily included in the same system;
- Probably the quickest system to institute because it requires no new construction or technical advances;
- Adaptable to new advances like computer-controlled functional inspection and diagnosis;
- Has a built-in enforcement tool--the operational checklist;
- Is effective in controlling average emissions without the use of a sanction which would trigger the individual-car warranty provisions of the Act with its attendant quagmire (see pp. 80 to 88 of Ref. 1);
- Can be operated in existing garages, in state-operated facilities or partially in both.

As indicated, enforcement in this system operates through the mechanism of a checklist of items which must be covered during functional inspection, repair and maintenance. A copy of this checklist signed by a government inspector or a licensed mechanic is proof of compliance and is either required at annual vehicle registration or must be carried in the vehicle at all times.

The logbook system now used in Japan[24] is a good example. Each new car is delivered with a service record book which includes duplicate pages detailing the items to be covered during the safety and emissions checks every six months. The checklists are quite complete, with the list for the 12-month inspection being more complete than for the 6-month or 18-month inspections and with the list for 24 months being the most complete. These required inspections can be performed by any licensed mechanic or by government inspectors at 72 stations operated by the Ministry of Transport, with the exception that only a government inspector or a mechanic with the advanced license can perform the 24-month inspection. The mechanic or inspector indicates on the checklist which items are in correct adjustment or condition and which items need repair or adjustment. He then signs the inspection list with his name and license number and mails the original to the control office. The duplicate remains in the owners logbook as proof that the car passed the inspection. This logbook is required to be in the vehicle at all times, similar to a registration in the United States, and stays with the car throughout its life. The system appears to be accomplishing its purpose judged on the basis that only about 2% of the cars fail the difficult 24-month inspection after minor adjustments. This should be compared with 25% of the vehicles which fail a second inspection in New Jersey after having failed the first inspection and having been sent for adjustment or repair. If there is a significant difference in the stringency of standards, the Japanese standards are the more stringent. On the basis of what has been seen, the Japanese system appears to be the most successful at maintaining proper adjustment. The requirement that the inspection record must be in the car and available for inspection by an officer at all times is probably a more effective deterrent of intentional device deactivation than a simple yearly inspection. It is questionable that a yearly inspection would reduce device deactivation significantly, if the incentive in performance or mileage were large.

Either this approach or proof of compliance at registration could be operational in California, which has licensed Class A mechanics, within a few months. This type of regime could be operational within a year in other governmental jurisdictions, Chicago for example, which already have legal authority to license mechanics. Passing the necessary legislation would at least double this time. Other favorable characteristics have been listed.

Unfortunately, this type of regime is probably not viable under present conditions because of the public's distrust of the service industry. This means that although this regime is one that could be made operative fairly soon from a technical standpoint, the need to dispel the public distrust makes it a long-term option like the other two types. This is perhaps the clearest example of how social attitudes are affecting the probability of cars meeting the emissions standards in the near future.

12.4 Type II - Adjustment Or Repair of Cars Exceeding Predetermined Emission Standards

This regime includes:

- An inspection to determine whether exhaust emissions are exceeding specified standards;
- Diagnosis of why the vehicle is exceeding standards;
- Repair or adjustment to pass the standards on re-inspection;
- Enforcement by requiring that cars pass inspection if they are to be driven.

This regime has the following characteristics:

- Is mandatory for all cars;
- Does not ensure all types of maintenance--preventive maintenance and manufacturer's specified maintenance are not included;

- Probably requires new construction, because of reluctance to have an inspection, which may result in either a repair bill or a sanction, performed by the mechanic doing the adjustment or repair;
- Applicable to new and existing cars but will require different inspection tests and standards for the two groups;
- Safety items are easily included;
- Takes longer to implement than the previous system because of more complex legislative action before authorization and because of probable new construction;
- Adaptable to new technical advances;
- Enforcement is on the basis of a sanction which probably would trigger the individual-car warranty provisions of the Act;
- Can be operated exclusively in existing garages, in state-operated facilities or partially in both--the last case is most probable;
- Practical considerations require pass-fail standards which pass cars emitting more than the amount which will ensure that the average car meets the official standards, thus reducing the probability of this regime ensuring that the standards will be met;
- May require less direct governmental control of the competency of mechanics than the first system.

A typical example of this system is the New Jersey state-operated inspection-lane method. It is most attractive in those cases where the emissions inspection can be added to operating safety inspection lanes. Under these conditions it can probably be operational within one to two years after enabling legislation becomes effective. If the regime must be developed in its entirety, the time for implementation would increase to a minimum of five years, even with a favorable political climate. It has taken New Jersey over seven years, even though they started with safety inspection lanes in operation and a public which had been accustomed to an annual inspection since 1938.

The most apparent trouble spots with this method should be more clearly recognized because there has been a tendency to ignore them in the general acceptance of inspection/maintenance as the only viable regime. The effectiveness and viability have not been proved. In this method, it is essentially impossible to adjust the pass-fail inspection standards to fail only a reasonable percentage and at the same time ensure that the official standards will be met. Actually, use of this regime probably guarantees that the average emissions will be at least a little above the official standards. This method also fails to ensure the performance of either the recommended or preventive maintenance, another factor which will probably contribute to the standards being exceeded. The use of a sanction which invites the individual-car-warranty bureaucratic quagmire may be a political liability which hinders its use.

12.5 Manufacturing Cars Which Force the Repair of Inoperative Devices

This regime depends on the manufacture of cars which either:

- Have signals that alert regular law enforcement officers that an important emissions-control device is not operating; or
- Have systems that degrade the performance so markedly when an important emissions-control device is not operating that the owner is essentially forced to correct the deficiency.

This regime has the following characteristics:

- Is mandatory for all cars;
- Does not ensure either preventive maintenance or manufacturer's specified maintenance;
- Requires no new construction;
- Applicable only to new cars;
- Safety items are not easily included;
- Requires new technical advances;

- Requires less governmental control of the competency of mechanics than either of the first two regimes--fraud prevention is the only requirement;
- Would not trigger the individual-car-warranty provisions of the Act;
- Has a built-in enforcement tool;
- Would probably ensure that cars similar to the 1975-76 configuration with catalytic controls met the standards.

Dependence on new technology makes this type a possible option only for the long term. It is not clear that it is technologically feasible, but it probably is. There are many attractive features: no new construction, minimum governmental bureaucracy, and a built-in system of forcing the service industry to improve without licensing.

12.6 Summary

Since most governmental jurisdictions in the United States do not have mechanisms for enforcing proper maintenance, since the regime which could be instituted most quickly is precluded by a social attitude, and since the record indicates a time of at least five or six years to institute a New Jersey-type regime, the probability of having nationwide enforcement of proper maintenance by 1980 is vanishingly small.

12.7 Common Requirements for Maintenance of 1975-76 Cars

Items which are common to all the maintenance regimes regardless of which model cars are involved have been discussed in Subsection 12.1. This subsection discusses three items which apply particularly to the maintenance of 1975-76 vehicles.

12.7.1 Test of catalyst activity: The importance of detecting and correcting inactive catalysts has been emphasized in Subsection 7.2.

Unfortunately, the spread in the level of exhaust emissions ahead of the catalyst, even among vehicles of the same class, makes it impossible to do this reliably with a simple measurement with an infrared instrument of the exhaust emissions after the catalyst. For example, contaminant levels entering the catalyst can vary by a factor of two or more so it is impossible to distinguish a clean engine with an inactive catalyst from a dirty engine with an active one. Simple reliable methods are being investigated and at least one appears applicable. Causing one cylinder to misfire for about 30 seconds introduces about 2,000 to 3,000 ppm HC into the catalyst, and with this input concentration an infrared measurement of the exhaust will detect inactive catalysts.

12.7.2 Detection of lead poisoning: Since the present catalysts will recover from lead poisoning of short duration, it would be advisable to have a method for distinguishing between catalysts which are temporarily inactive due to short-duration lead exposure and ones which are permanently inactive. A test of the gasoline for lead may not be conclusive, since previous tankfulls may have contained the lead. Two activity tests separated by several tankfulls of unleaded fuel may be the best approach. This would avoid the time and cost of unnecessarily replacing a catalyst.

12.7.3 Diagnosis by measurement of exhaust emissions: Two studies[25,26] have shown the value of exhaust measurements as an engine diagnostic tool. To use this method for the proper adjustment of the engine, it is necessary to measure the exhaust uninfluenced by the catalyst. This would require a sampling port ahead of the catalyst. It is being supplied by only one of the domestic manufacturers and some of the foreign ones. Other engine-adjustment methods are being recommended, but they may not be as suitable under all conditions.

13. DIFFERENCES IN MAINTAINABILITY RESULTING FROM DIFFERENT ENGINES, EMISSIONS-CONTROL SYSTEMS, OR FUELS

This section presents the evidence and reasoning supporting Conclusion 10: There do not appear to be any engine-control-system combinations which are clearly superior in meeting the standards under the present inadequate maintenance situation.

Since the evidence indicates that cars powered by conventional internal combustion engines and equipped with either catalytic or non-catalytic emissions-control systems will not meet the standards under existing maintenance conditions, the question naturally arises whether there are other approaches which would come significantly closer to meeting the standards under these conditions. Two classes of evidence bearing on this question will be discussed: differences in cost of the recommended maintenance and an analysis of the effects of the variations in engines, control systems and fuels.

13.1 Differences in Cost of Recommended Maintenance

A partial answer to the above question can be obtained by comparing the costs of the manufacturers' recommended maintenance. These costs were estimated by members of the Panel of Consultants on Technology for the 23 configurations used in the Consultants Report on Manufacturability and Costs of Proposed Low-Emission Automotive Engine Systems.[27] The estimates were based on known costs for 1974 configurations. These 23 configurations included, in various combinations: conventional engines, non-catalytic controls, EGR, oxidation catalysts, reducing catalysts, three-way catalysts, stratified-charge engines (three kinds), advanced carburetors, electronic fuel injection (EFI), mechanical fuel injection (MFI), diesel engines, thermal reactors, and control of air/fuel ratio by both open and closed loop.

First, it should be remembered that these are estimates of the cost of recommended scheduled maintenance which may not be the same as the maintenance required to ensure meeting the standards. Second, the amount of recommended maintenance is only an indication, not a direct measure, of how well the car will meet emissions standards under existing maintenance conditions. Nevertheless, these costs should indicate any large differences in the maintainability of the configurations, if they exist. The configurations which use unleaded fuel all have lower estimated maintenance costs than those using leaded gasoline and this difference appears to be real when judged against the much smaller differences in costs among the members of either the "leaded" or "unleaded" groups taken separately. Except for this difference caused by lead, there do not appear to be any differences which would indicate a significant advantage for one or more configurations in terms of maintainability under existing conditions. One apparent exception, which will be discussed below, is the diesel, the recommended maintenance for which costs about 33% less than that for a comparable-size gasoline engine.

13.2 Analysis of Effects of Principal Variations in Engines, Emissions Control Systems, or Fuels

A more direct approach to answering the question as to whether one or more configurations would more nearly meet the standards under existing maintenance conditions is analysis of the effects of the principal variations in engines, emissions-control systems, and fuels.

Diesels: As noted above, the yearly scheduled maintenance for a diesel appears to be significantly less than for other engines. This difference may have been magnified by the interplay of the fact that the maintenance used in the cost estimates covers only the 50,000-mile warranty period and the fact that diesels require less frequent but more costly

maintenance. For example, the first major service on a properly functioning fuel-injection system would probably not come until after 50,000 miles, but it is comparatively expensive. The diesel reputation for durability and long life is based to an appreciable extent on the fact that they are manufactured specifically for end uses where durability is more important then first cost and where they are likely to receive the service which is necessary to ensure durability.

Ricardo and Company, Engineers, Ltd pointed out to the members of the Panel of Consultants on Engine Systems on 17 June that diesels require less frequent tune-ups but more frequent oil changes, and that the use of EGR introduces abrasive soot in diesels. It is not clear whether the durability of diesels will be maintained, if the present heavy construction is altered to obtain a lighter and less costly engine for passenger car use on a larger scale. The combination of high-pressure stresses, lighter-weight construction, and the tendency of the non-commercial owner to neglect service might easily result in the diesel exceeding the standards as quickly as other engines. Widespread introduction of diesels would require some additional training of mechanics even though servicing of the injector systems would probably not be done in the field.

Honda CVCC: The Honda version of stratified charge is to a large extent a conventional engine with an extra valve per cylinder, an extra carburetor, and a special exhaust manifold which acts as a thermal reactor. Data are not available on the performance of this engine in use, but the design indicates that this engine should be neither more nor less able to maintain emissions control under existing conditions than conventional engines using non-catalytic control. The presence of the extra carburetor might appear to be the source of extra difficulty, but this is at least partially avoided by locking the adjustments on the main carburetor and adjusting only the secondary one. It can also be

argued that the Honda engine trades the difficulties of an EGR system, which is not used, for the difficulties associated with the second carburetor.

Rotary engines: The emissions-reduction systems used on rotary engines are similar to those used on conventional engines (see Section 9 on rotary engines in Reference 4). Depending upon the manufacturer, the systems use either catalytic or thermal reactors and EGR. Since the concentration of HC in the raw exhaust from some rotary engines is much higher than that in exhaust from conventional engines, the catalyst must maintain high conversion efficiency to meet the standards and there is concern on this point. The thermal reactors appear to have low deterioration factors, but there has been some trouble with flame-out when the air/fuel ratio drifts away from the design value. The stresses connected with high temperatures are also always a source of potential trouble. There is certainly no indication that rotary engines are more likely to maintain low emissions than conventional engines under existing conditions.

Gas turbines: There are no data to indicate how well gas turbines would maintain low emissions in light-duty vehicle applications. A gas turbine appears to be less complicated than a conventional engine, but some potential maintenance trouble spots exist. From an emissions-control standpoint, the principal one is probably the combustor, particularly the variable-geometry combustors needed to attain low NO_x emissions. The continuously variable transmission and high-temperature ceramics are others, but the emissions impact of trouble in these areas is not known. Since continuous combustion is inherently cleaner than the intermittent combustion used in conventional engines, the turbines may have an advantage with regard to maintaining low emissions, but this has not been proved and it may depend on the level of the NO_x standard.

Rankine engines: Rankine-cycle engines are also continuous combustion and, consequently, enjoy the advantage of inherently cleaner combustion. Low emissions have been demonstrated in a small car (see Section 12 on alternative power plants in Ref. 4). Maintenance of the combustor to design specifications appears to be the only requirement for low emissions and this should be easier than in the case of the turbine, since variable geometry is not required. This engine appears to have advantages from the standpoint of maintaining low emissions with minimum service.

Stirling engines: This is the third continuous-combustion engine which may be introduced in the future (see Ref. 4) and it is also inherently cleaner than conventional engines. The principal maintenance problems appear to be thermal stresses, leakage of the working fluid, and high-temperature ceramics, and none of these should have a direct effect on emissions. This engine also appears to be one which could maintain low emissions with minimum service.

PROCO system: The Ford programmed combustion system is another stratified-charge engine. Development at the present time is based on the use of an oxidation catalyst so it is similar to conventional engines in this regard. In addition, HC emissions are sensitive to the use of EGR to control NO_x emissions, and with sufficient EGR to attain 0.4 g/mi NO_x, the HC standard is exceeded at high mileage. This system cannot be expected to maintain low emissions under conditions of minimum service.

Texaco TCCS engine: This stratified-charge engine also uses an oxidation catalyst for the control of HC and CO emissions. Control of NO_x emissions from the TCCS engine do not appear to adversely affect the HC emissions as they do in the PROCO. However, the emissions are sensitive to the timing between fuel injection and plug firing, and the

ignition system is subject to more severe service conditions than in a conventional engine. This engine does not appear in any way superior to conventional engines in it's ability to maintain low emissions under existing service conditions.

Electric cars: Electric cars transfer the pollutant source from the vehicle to the generating plant so that maintenance of the car for low emissions is not a question. This fact should not be automatically interpreted as meaning that the pollutant burden in metropolitan centers would be reduced by the use of electric cars, since this depends on the source of the primary power.

Advanced carburetors: Improvements in carburetor design should result in inherently cleaner combustion, but this does not mean that these carburetors will make it easier to maintain low emissions without proper service. Actually, the reverse is indicated since most of the improved designs are more complicated. For example, one of the more promising new designs, a sonic carburetor, has high actuation forces which cause high component wear (see Section 5 on mixture preparation in Ref. 4).

Fuel Injection: Electronic fuel injection appears to be somewhat more complicated to maintain in adjustment than a conventional carburetor and mechanical fuel injection appears to be less difficult. Both of these systems would require additional training of the service personnel, so that neither one would make it easier to maintain low emissions under existing conditions.

Closed-loop control of air/fuel ratio: Closed-loop control of air/fuel ratio is essentially self tuning in that it corrects for deviations from specifications in the fuel-metering equipment. Because of this feature, it should reduce the maintenance required to maintain

low emissions. Since it is often part of a system including electronic fuel injection and must be part of a system using a three-way catalyst, the advantage is sometimes attributed to these other components in error.

Hydrogen: Hydrogen as a fuel essentially eliminates HC and CO emissions, but NO_x emissions are similar to those with gasoline as a fuel and the emissions are affected by engine variables in much the same way (see Section 12 on alternative fuels in Ref. 4). If NO_x emissions are not the problem, hydrogen offers the potential for low emissions with minimum maintenance. It should be noted, however, that it would require additional training of mechanics and that it merely transfers the pollutant problem to another power source.

Methanol: Federal test-cycle evaluations with 10% methanol in gasoline indicate a 50% reduction in CO, a 10% reduction in NO_x, and essentially no change in HC emissions. Pure methanol as a fuel allows operation at leaner mixtures and this results in significant reductions in HC and CO, a small reduction in NO_x, and an increase in aldehyde emissions. This fuel requires close control of mixtures and of mixture distribution. Methanol offers no obvious advantage from the standpoint of easily maintained low emissions.

REFERENCES

1. "Feasibility of Meeting the 1975-1976 Exhaust Emission Standards in Actual Use," prepared by the Panel on Testing, Inspection, and Maintenance for the Committee on Motor Vehicle Emissions, Washington, D.C., June 1973.

2. 42 U.S.C. § 1857f - 6a(c) (1970).

3. "Consultant Report to the Committee on Motor Vehicle Emissions on Emissions and Fuel Economy Test Methods and Procedures," Washington, D.C., September 1974.

4. "Consultant Report to the Committee on Motor Vehicle Emissions on Emissions Control of Engine Systems," Washington, D.C., September 1974.

5. Visits on 5, 6, and 7 June 1974 to American Motors, Chrysler, Ford and General Motors.

6. Visit to Universal Oil Products on 16 April 1974.

7. Visit to Robert Bosch GMBH, Stuttgart, West Germany on 21 June 1974.

8. Visit to Gould, Inc., Cleveland, Ohio, on 9 July 1974.

9. Status Review - General Motors Closed-Loop Emission Control Program, 6 June 1974.

10. Data supplied by General Motors on 6 June 1974.

11. Data supplied by Ford on 7 June 1974.

12. Conference with the Automotive Service Industry Association (ASIA) in Chicago on 15 April 1974.

13. "Maintainability and Repairability of Vehicles in Use - Summary Report," Vol. 1, National Highway Traffic Safety Administration, Department of Transportation, June 1971.

14. Presentation before the State of Michigan House Committee on Consumer Affairs and Agriculture, 13 May 1974.

15. Letter from F.W. Bowditch, General Motors, to R. Robert Brattain dated 12 June 1974.

16. Statements made by ASIA and the Automotive Service Council, 15 April 1974.

17. National Institute for Automotive Service Excellence (NIASE) press release, 12 August 1974.

18. Wall Street Journal, 26 June 1974.

19. Washington Post, 28 February 1974.

20. "Automobile Exhaust Emission Surveillance - Analysis of the FY-72 Program," EPA 460/2-74-001, February 1974.

21. "Exhaust Emissions from Privately Owned 1966-1972 California Automobiles, A Statistical Evaluation of Surveillance Data," California Air Resources Board, October 1973.

22. "Consultant Report to the Committee on Motor Vehicle Emissions on an Evaluation of Catalytic Converters for Control of Automobile Exhaust Pollutants," Washington, D.C., September 1974.

23. Letter from D.L. Hittler, American Motors, to David Litvin, Federal Energy Office, 8 May 1974.

24. Discussions with Japanese governmental agencies and the Japan Automobile Manufacturers Association, 7 to 10 May 1974.

25. "An Evaluation of the Effectiveness of Automobile Engine Adjustments to Reduce Exhaust Emissions," California Air Resources Board Contract ARB-654, Clean Air Research Co., June 1973.

26. "Mandatory Vehicle Inspection and Maintenance," ARB Contract 1522, Olson Laboratories, December 1971.

27. "Consultant Report to the Committee on Motor Vehicle Emissions on Manufacturability and Costs of Proposed Low-Emissions Automotive Engine Systems," Washington, D.C., November 1974.

APPENDIX A

Organizations Contacted by Members of the Panel of Consultants on Field Performance and Maintenance

1.	EPA, Ann Arbor, MI (advanced power plants group)	1/22/74	*Brattain
2.	EPA, Ann Arbor, MI (emission control technology division)	1/23/74	Brattain
3.	Chrysler Corp., Detroit, MI	2/12/74 & 6/5/74	Brattain, Gockel, McDowell
4.	Ford Motor Co., Dearborn, MI	2/13/74 & 6/7/74	Brattain, Gockel, McDowell
5.	General Motors Corp., Warren, MI	2/14/74 & 6/6/74	Brattain, Gockel, McDowell
6.	California Air Resources Board El Monte, CA	3/20/74	Brattain, Gockel
7.	Dresser Industries, Santa Ana, CA	3/21/74	Brattain
8.	Philco-Ford, Newport Beach, CA	3/21/74	Brattain
9.	ARCO Research Center, Harvey, II	4/15/74	Brattain
10.	Automotive Service Council, Chicago, IL	4/15/74	Brattain
11.	Automotive Service Industry Association, Chicago, IL	4/15/74	Brattain
12.	Dept. of Environmental Control, Chicago, IL	4/15/74	Brattain
13.	National Institute for Automotive Service Excellence, Chicago, IL (representatives and correspondence with the national headquarters)	4/15/74	Brattain
14.	Universal Oil Products, Des Plaines, IL	4/16-17/74	Brattain

*Last names of Panel Members.

15.	Environment Canada, Ottawa,Ontario (mobile sources division, air pollution control directorate)	4/18/74	Brattain
16.	Bureau of Motor Vehicle Pollution Control, Brooklyn, NY	4/19/74	Brattain, McDowell
17.	City of New York, Long Island, NY (taxi & limosine inspection station)	4/19/74	Brattain, McDowell
18.	New York State Dept. of Environmental Conservation, Albany, NY, (bureau of air quality control)	4/22/74	Brattain, McDowell
19.	New York State Dept. of Motor Vehicles, Albany, NY	4/22/74	Brattain, McDowell
20.	New Jersey State Dept. of Environmental Protection, Trenton, NJ, (bureau of air pollution control)	4/23/74	Brattain, McDowell
21.	Cypress College, Cypress, CA	4/26/74	Gockel
22.	Automotive Service Systems Group, Applied Power, Inc., Milwaukee, WI	5/2/74	McDowell
23.	Pennsylvania Dept. of Transportation, Harrisburg, PA	5/3/74	McDowell
24.	Air Quality Bureau Environment Agency Tokyo, Japan, (automotive pollution division)	5/7/74	Brattain
25.	Dept. of Environmental Services, Washington, DC	5/8/74	McDowell
26.	Honda Motor Co., Tokyo, Japan	5/8/74	Brattain
27.	Ministry of Transport, Tokyo,Japan, (environmental pollution control division, motor vehicle division, road transport bureau)	5/8/74	Brattain
28.	Dept. of Motor Vehicles, Washington, DC	5/8/74	McDowell

29.	Japan Automobile Manufacturers Association, Tokyo, Japan	5/10/74	Brattain
30.	So. Calif. Auto Club, Los Angeles, CA	5/14/74	Gockel
31.	Yellow Cab Taxi Fleet, Los Angeles, CA	5/14/74	Gockel
32.	IGO, Los Angeles, CA	5/15/74	Gockel
33.	National Highway Traffic Safety Administration Research Inst., Washington, DC	5/15/74 5/20/74	McDowell
34.	TRW, Redondo Beach, CA	5/20/74	Gockel
35.	Bureau of Auto. Repairs, Sacramento, CA	5/23/74	Gockel
36.	National Institute for Automotive Service Excellence, Washington, DC	6/3/74	McDowell
37.	American Motors, Detroit, MI	6/5/74	Brattain, Gockel, McDowell
38.	Colorado Dept. of Health, Denver, CO (air pollution control division)	6/10/74	Brattain, Gockel
39.	Colorado State University, Denver, CO (conference)	6/12/74	Brattain,
40.	EPA, Denver, CO (Rocky Mountain-Prairie Region)	6/12/74	Brattain,
41.	Dept. of the Environment, London, England	6/17/74	Brattain
42.	Direction des Routes et de la Circulation Routiere, Ministere de l'Equipement et du Logement, Paris, France	6/18/74	Brattain
43.	Union Technique de l'Automobile du Motorcycle et du Cycle, Autodrome de Linas- Montlhery, outside of Paris, France	6/18/74	Brattain

44.	Verband der Automobilindustrie, Geneva, Switzerland (conference)	6/19/74	Brattain
45.	A.B. Svensk Bilprovning, Stockholm, Sweden	6/24/74	Brattain
46.	Shell Oil Co., Houston, TX (environmental affairs)	9/24/74	Brattain
47.	EPA, Research Triangle Park, NC	10/1/74	Brattain
48.	San Diego County, San Diego, CA (fleet operations)	5/21/74	Gockel
49.	Arizona State Dept./Health, Phoenix, AZ, (vehicular emissions)	6/10/74	Gockel

U.S. GOVERNMENT PRINTING OFFICE: 1975— 582 419 222